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Irrigation Demand in the Utah Lake Drainage Area the Role of Irrigation Efficiency

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IRRIGATION DEMAND IN THE UTAH LAKE DRAINAGE AREA

THE ROLE OF IRRIGATION EFFICIENCY

by

Hiro Mizue

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NOMENCLATURE

Symbol	Definition
AC1	crop area, percent of total crop area
AGSC	crop growth stage coefficient
ASMS	accumulated soil moisture supply, acre-feet
ARZS	adjusted water supply to root zone, acre-feet
CC	precipitation adjustment coefficient
CD	canal diversion, acre-feet
CT	temperature adjustment coefficient
DEM	monthly demand at specified irrigation efficiency, acre-feet
DEMA	annual demand at specified irrigation efficiency, acre-feet
DF	monthly deficit at specified irrigation efficiency, in which mean diversion, precipitation, and root zone storage are included, acre-feet
DFA	annual deficit at specified irrigation efficiency in which mean diversion, precipitation, and root zone storage are included, acre-feet
DFAS	annual deficit at specified irrigation efficiency; applicable to Utah Valley subarea and Utah Lake drainage area where water is assumed to be applied uniformly over entire area, acre-feet
DFAZ	annual deficit at specified irrigation efficiency in which precipitation and root zone storage is neglected, acre-feet
DFS	monthly deficit at specified irrigation efficiency; applicable to Utah Valley subarea and Utah Lake drainage area where water is assumed to be applied uniformly over entire area, acre-feet

NOMENCLATURE (Continued)

Symbol	Definition
E_A[a]	application efficiency, percent
E_C	water conveyance efficiency, percent
E_I	irrigation efficiency ($E_S E_C E_A$), percent
E_S	reservoir storage efficiency, percent
EI	irrigation efficiency, percent
F	Blaney-Criddle monthly consumptive use factor
GSC	crop area including growth stage coefficient effect, acre-feet
I	subscript denoting month
PCL	adjusted precipitation on cropland, acre-feet
PCUD	potential consumptive use deficit, acre-feet
PDH	monthly percentage of daylight hours in the year
PREC	mean monthly precipitation, inches
RZS	diverted water to root zone, acre-feet
SGSC	growth stage coefficient
SMC	soil moisture capacity, acre-feet
SMS	soil moisture supply, acre-feet
SPCU	total monthly potential consumptive use, acre-feet
SR	monthly surplus at specified irrigation efficiency in which mean diversion, precipitation, and root zone storage are included, acre-feet
SRA	annuan surplus at specified irrigation efficiency, in which mean diversion, precipitation, and root zone storage are included, acre-feet

NOMENCLATURE (Continued)

Symbol	Definition
SRAS	annual surplus at specified irrigation efficiency; applicable to Utah Valley subarea and Utah Lake drainage area where water is assumed to be applied uniformly over entire area, acre-feet
SRAZ	annual surplus at specified irrigation efficiency in which precipitation and root zone storage is neglected, acre-feet
SRS	monthly surplus at specified irrigation efficiency; applicable to Utah Valley subarea and Utah Lake drainage area where water is assumed to be applied uniformly over entire area, acre-feet
STR	storage in root zone available, acre-feet
TAVE	adjusted monthly temperature, degrees Fahrenheit
TEMP	monthly temperature, degrees Fahrenheit

ABSTRACT

Irrigation Demand in the

Utah Lake Drainage Area:

The Role of Irrigation Efficiency

by

Hiro Mizue, Master of Science

Utah State University, 1968

Major Professor: Gaylord V. Skogerboe
Department: Civil Engineering

The effect of irrigation efficiency upon the water demand for agricultural purposes in the Utah Lake drainage area has been evaluated in this study. Irrigation demand is the quantity of water at the supply source necessary to satisfy crop water requirements, taking into account irrigation efficiency.

The Utah Lake drainage area was divided into hydrologic subareas and districts to facilitate analysis. The demand, surplus, and deficit quantities for each area was determined. The computations were made using constant mean quantities. Within a given area, the diverted water was assumed to be applied uniformly to satisfy agricultural crop demands, and the contribution of groundwater was neglected.

The quantity of major interest is the surplus or deficit, which has been computed for present and potential future irrigation efficiencies taking into account historical diversions and precipitation, and estimated root zone storage. The crop demand is not adequately met in the study area. There is a surplus in the Provo district (29,000 acre-feet annually), while deficits occur in the Spanish Fork district (69,000 acre-feet annually) and Northern Juab Valley subarea (38,000 acre-feet annually). The common pattern is excessive diversions in May and insufficient diversions in July through September. The present mean irrigation efficiency of 36 percent in the Utah Lake drainage area results in an annual deficit of 111,000 acre-feet, of which 69,000 acre-feet occurs in Utah Valley. The maximum monthly deficit is 76,000 acre-feet, which occurs in August.

Provided irrigation efficiencies were increased to 68 percent, surplus would exist in every month and the annual surplus would be 159,000 acre-feet. The combination of additional storage facilities to modify the diversion to coincide with crop demand, reallocation of water from water-plenty to water-short areas, and increasing the irrigation efficiency would provide the best economic use of water for the benefit of the area.

(169 pages)

CHAPTER 1

INTRODUCTION

Purpose

The purpose of this study is to determine how irrigation efficiency quantitatively affects the irrigation water demand of the Utah Lake drainage area. Irrigation efficiency is the ratio of the volume of water necessary for crop use to the total volume of water diverted, stored, or pumped for irrigation. Irrigation demand is the quantity of water at the diversion point which either is necessary for crop use or is in excess of the crop needs. Explanations of these terms are given in Chapters 3 and 4. The irrigation surpluses and deficits under mean diversion quantities and demands are determined for the several subareas within the drainage area. Technical improvements in the conveyance and application of water may increase efficiency. As part of this study the irrigation surpluses and deficits will be determined for various estimated future efficiencies.

In most hydrologic calculations involving irrigated lands, efficiency is arbitrarily assumed. Consequently the crop needs and the hydrologic components (e.g., groundwater, runoff, etc.) may be overestimated or underestimated. This study does not present any new efficiency data, but rather presents the quantities of water diversions required for various degrees of efficiency. In this way, the role of irrigation efficiency can be placed into perspective.

The effect of irrigation efficiency on water resources is an important and timely topic. Competitive pressures from non-agricultural sources may eventually force the irrigator to either give up lands to enterprises which offer greater economic gain or to increase the efficiency in the use of resources in order to attain greater productivity. Thus, the individual and collective irrigator of agricultural areas may be encouraged to adopt new irrigation management techniques in order to use water more efficiently.

Irrigation is of importance both in the nation and in the west. In the United States, irrigation accounts for 46 percent of the water diverted and 94 percent of water consumptively lost through evaporation and transpiration (U.S. Congress, 1960a, Figure 7, p. 6). In the Great Basin and Colorado Basin, more than 90 percent of the water diverted is for irrigation purposes (U.S. Congress, 1960a, Figure 6, p. 5). This indicates that irrigation efficiency is of significance in the management of water resources.

Hydrologically, irrigation efficiency in a large drainage basin is not truly meaningful because the water remains within the basin and may be available for other uses (Bagley, 1965, p. 70). However, irrigation efficiency is important on a short time basis since it affects both the available quantities and the institutional limitations on diversions. Water rights are determined by specific quantities available at certain times. Temporary water depletion may be harmful financially. The quantity in the watercourse may be reduced, due to excessive upstream diversions, which in turn will affect the quantity divertable under the water right. The result may be decreased crop production and, over a long period, larger and more expensive irrigation facilities (canals, reservoirs, pumps) will be required to convey greater water quantities.

In the Utah Valley, inefficiency at higher elevations does contribute some root zone water through seepage and surface runoff to lower elevation lands. But a large fraction of this waste enters into the groundwater, flows into Utah Lake, and may not be economically recoverable for irrigation purposes. Provided upstream users possess highly efficient conveyance and application systems, their diversions can be limited. This leaves greater quantities in the water-course for economic retrieval downstream or for conveyance to areas outside the riparian lands. These quantities may be used for other agricultural or alternative uses. Thus, efficiency may become a useful tool in the reallocation of water between small areas of a watershed. This will, in the end, benefit the agricultural productivity of the entire basin.

In summary, irrigation efficiency is important because (a) irrigation constitutes a significant water use in the Great Basin, (b) higher efficiencies decrease the cost of transporting and storing large water quanties, and (c) higher efficiencies make possible re-allocation of water to other areas or other uses to benefit the economy.

Scope

This study will cover the effects of varying degrees of efficiency upon the irrigation diversion demand in the Utah Lake drainage system. No attempt is made to analyze the economic consequences of attaining certain efficiency values. Greater efficiency will undoubtedly increase water quality problems for downstream users but for the purposes of this study, the discussion will be limited to the quantitative aspect of water use. Recommendations regarding the best approach for attaining more efficient use of water, particularly on institutional and political aspects, are not included. Although it is recognized that all technical improvements depend upon institutional organization and changes, discussion of possible modifications have been omitted because no quantitative data is available (as determined by the writer).

The two important components of this study are the determination of annual demand as a function of irrigation efficiency and the recognition that water must be delivered to locations at times of greatest crop need. Actual diversion quantities and crop potential consumptive use data are conjunctively presented to illustrate their relationship. Comparisons are made between the subareas in the basin. The surpluses and deficits at the diversion point are determined by assuming uniform water distribution over the given area under mean conditons. Various efficiencies are assumed based upon irrigation practices and potential technical improvements and the surpluses and deficits are calculated for these efficiencies on both mean monthly and mean annual basis.

CHAPTER 2

DESCRIPTION

Location

The Utah Lake drainage area is located in the northern part of central Utah. The area is part of the drainage system tributary to the Great Salt Lake. The Great Salt Lake drainage area is in turn part of the Great Basin. The Utah Lake drainage area includes those lands above the stream gaging station designated as "Jordan River at Narrows."

The boundaries of the Utah Lake drainage area fall within five counties (Utah, Sanpete, Juab, Wasatch, and Summit), but the major part lies within Utah County. The areal dimensions are approximately 96 miles in a line running SW to NE from the Tintic Mountains to Bald Mountain, 61 miles NS through the city of Provo and 49 miles EW through Provo. The Utah Lake drainage area which is 3,092 square miles in size has been divided into subareas as shown in Figure 1. The largest hydrologic subarea is Utah Valley which covers an area of 957 square miles. The size of each subarea is listed in Table 1.

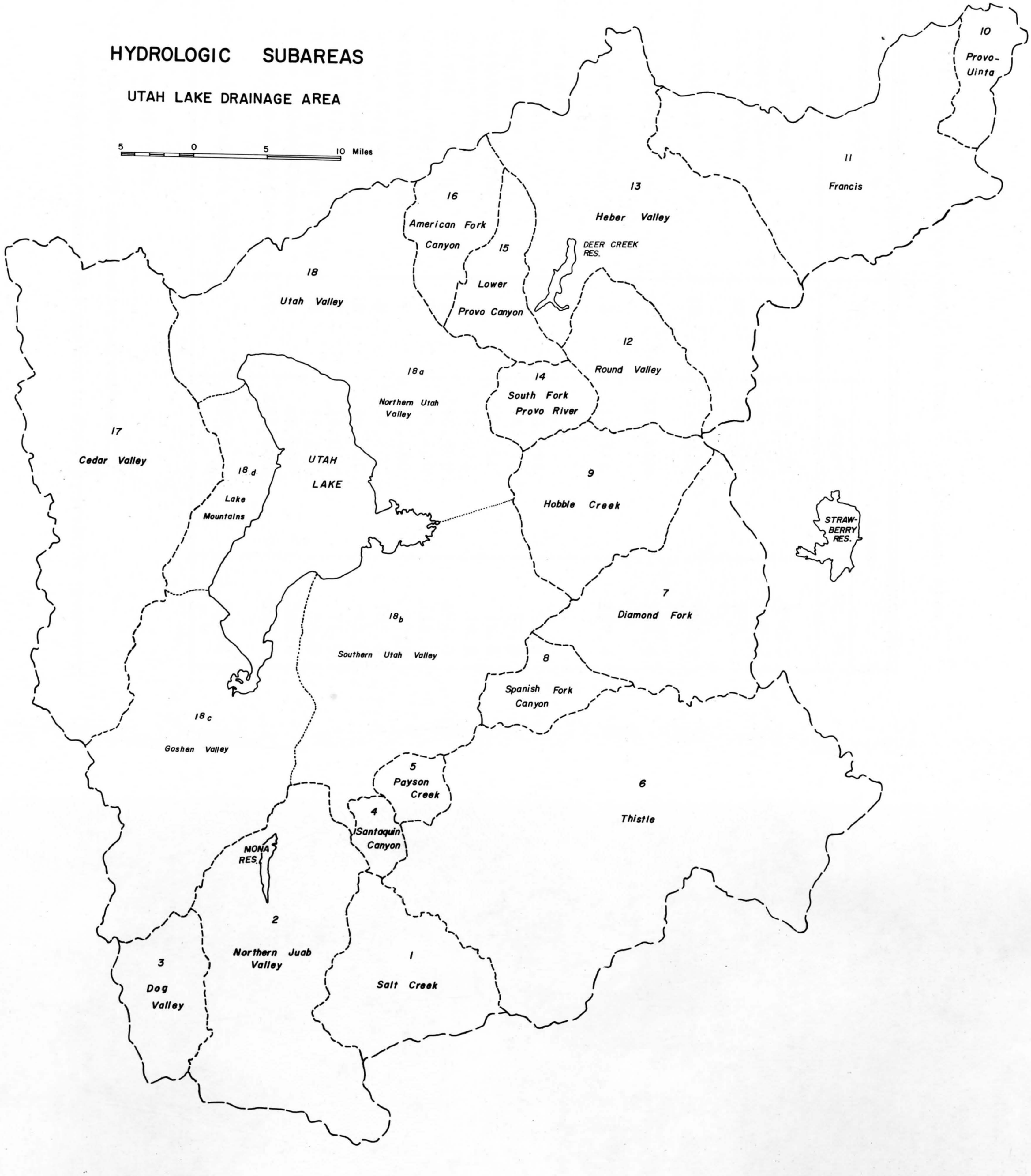

Fig. 1. Hydrologic subareas of Utah Lake drainage area.

Table 1. Hydrologic areas within the Utah Lake drainage area[a].

Hydrologic Area[b]	No.[c]	Area	
		Acres	Sq. Mi.
(Heber-Kamas)	--	293,120	458.0
Francis (Kamas)	11	129,920	203.0
Heber Valley	13	163,200	255.0
(Utah Valley)	18	612,480	957.0
Cedar Valley	17	201,600	315.0
(Northern Juab Valley)	2	132,736	207.4
Other areas			
Salt Creek	1	61,184	95.6
Dog Valley	3	35,776	55.9
Santaquin Canyon	4	9,344	14.6
Payson Creek	5	12,032	18.8
Thistle	6	290,560	454.0
Diamond Fork	7	93,440	146.0
Spanish Fork Canyon	8	23,680	37.0
Hobble Creek	9	67,200	105.0
Provo-Uinta	10	19,200	30.0
Round Valley	12	46,016	71.9
South Fork Provo River	14	19,200	30.0
Lower Provo Canyon	15	28,800	45.0
American Fork Canyon	17	201,600	215.0
(Utah Lake drainage area)	--	2,147,948	3,356.2

[a]Hyatt, et al 1968b.

[b]Areas in this study indicated by parentheses.

[c]Number refers to subarea designation in State hydrologic inventory.

Geography

The Utah Lake drainage area contains several hydrologic subunits which are important agriculturally. These are the Francis subarea (Kamas), Heber Valley, Utah Valley, (including Northern Utah Valley, Southern Utah Valley and Goshen Valley), Cedar Valley, and Northern Juab Valley. The lower elevation valleys west of the Wasatch mountain crest, popularly known as the Wasatch Front, constitute a highly important part of the drainage basin because of their fertility and population density.

Of the divisions referred to previously, Utah Valley is by far the largest in size. The valley is an intermontane basin situated at the eastern margin of the basin and range physiographic province (Bissell, 1963, p. 101). Utah Valley is bounded on the east by the Wasatch Mountains, on the west by the Lake Mountains and the low hills on the west side of Goshen Valley, on the south by low hills separating it from Juab Valley, and on the north by the Traverse Mountains. For the analysis of irrigation demand, Utah Valley is divided into three districts identified as Lehi-American Fork, Provo, and Spanish Fork. The Spanish Fork district includes both Southern Utah Valley and Goshen Valley. Within each subarea of Utah Valley there are service areas served by major water distributing canals or companies (Figures 2 and 3).

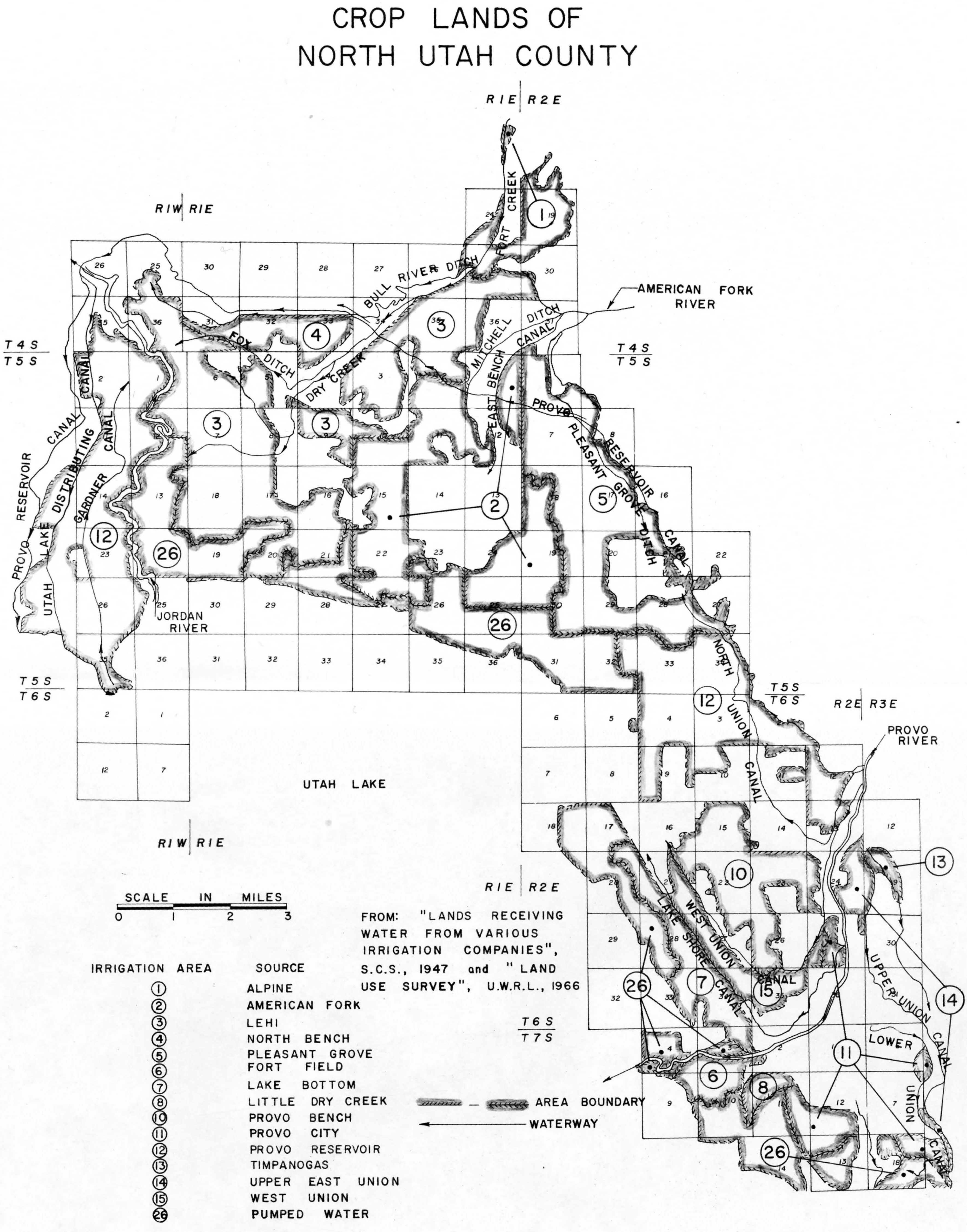

Fig. 2. Northern Utah County croplands.

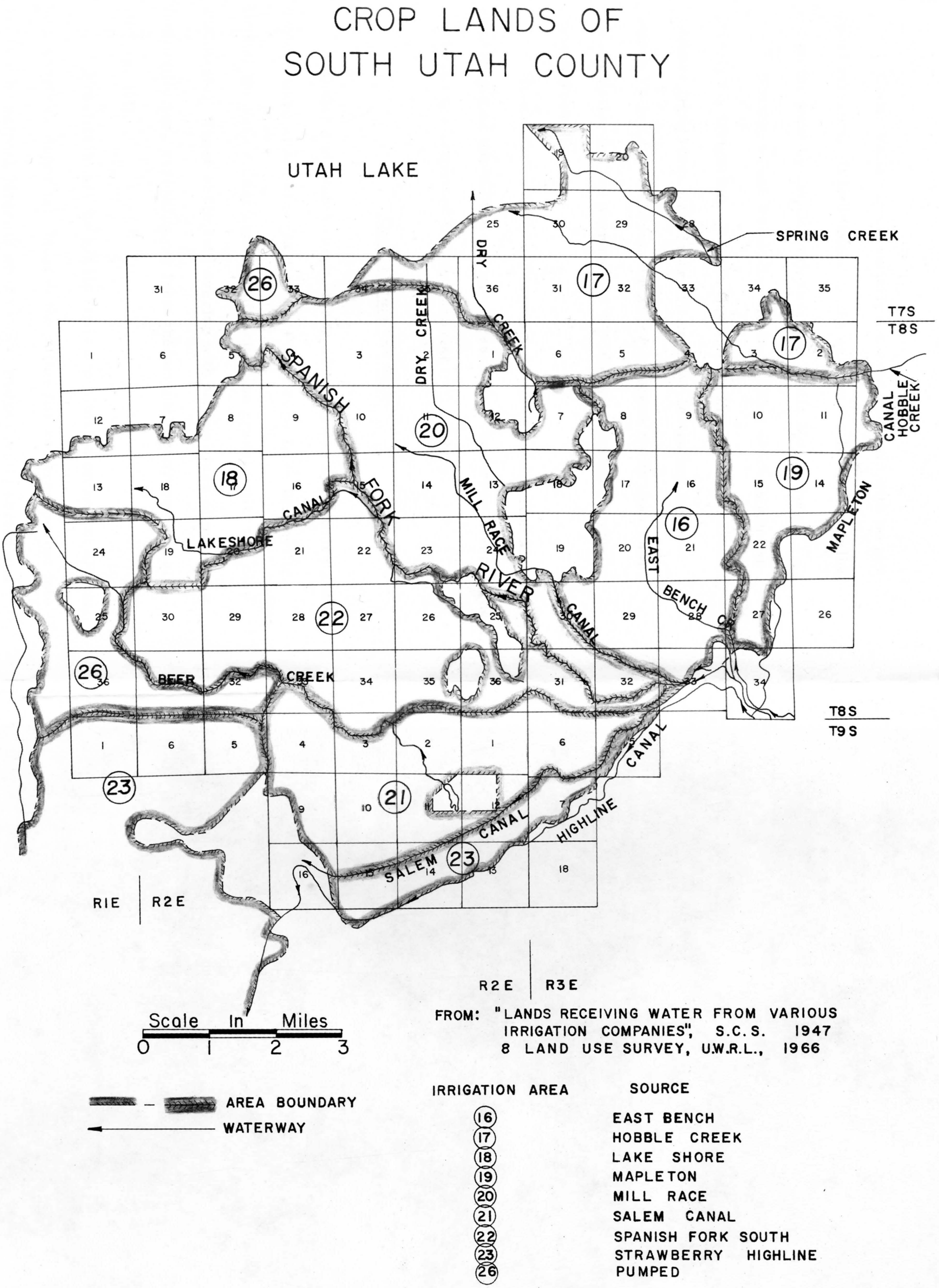

Fig. 3. Southern Utah County croplands.

Cedar Valley is essentially a closed subbasin with no perennial streams. It is bounded on the east by the Lake Mountains, and on the west by the Oquirrh and East Tintic Mountains.

Northern Juab Valley has limited inflow which is almost entirely for irrigation. Return flows drain into Mona Reservoir. Outflows from Mona Reservoir are used for irrigating lands in Goshen Valley, which is located at the southern tip of Utah Lake. Goshen Valley for the purposes of this study is included in the Spanish Fork district.

Heber Valley and the Francis subarea (southern Kamas Valley) are located on the middle and upper reaches of the Provo River. These two areas are combined into one district in this study.

Land Forms and Soil

Cedar and Utah Valleys, along with portions of Northern Juab Valley, were at one time part of the Pleistocene Lake Bonneville. Hence, the valley floor consists of lacustrine gravel, silt, and clay sediments. These sediments overlap with alluvial fans of pre-Lake Bonneville age, spreading out from the mountain canyons (Bissell, 1963, p. 101).

Practically all the arable lands are situated on recent alluvial and lacustrine deposits. Most of the valley fill was transported into the lake by entrant streams where it was hydraulically sorted and reworked, then deposited on deltas, benches or on the lake bottom (U.S. Dept. of Interior, 1964c, p. 9).

The surface features may generally be grouped into four types: benches, river bottoms, alluvial fans, and lake bottoms. Each type has characteristics which require distinct irrigation practices.

The benches are wide delta areas formed of highly permeable medium to coarse textured alluvium. The flat surface slope (average is rarely greater than 1.25%) and high elevation facilitates construction of canals but the elevation of these lands necessarily set them apart from other areas. Due to this arrangement they are served by separate canal companies (Hudson, 1962, pp. 14-15).

The river bottom soils are found in long narrow strips along the major rivers. The soils are permeable medium to coarse alluvium. Being set apart from the benches by the differences in elevation, they are provided with irrigation waters by canal companies formed to service only these lands (Hudson, 1962, pp. 16-17).

The alluvial fans are located at the mouths of rivers and along the base of mountain rims. They are of moderate slope (about 2 to 5 percent, except near lake bottoms where 1 percent is common) and are basically well drained alluvial material. However, much of the surface soil consists of lacustrine silt (Hudson, 1962, pp. 16-17).

The lake bottom borders the area around Utah Lake. The area is gently slopping and comprises the bulk of the Utah Valley lands.

Due to the flat slope and low elevation of these lands within the basin, drainage problems exist. The soils are fine to medium textured material, primarily silt and clay (Hudson, 1962, p. 18; U.S. Dept. of Interior, 1964c, p. 160).

Climate

The climate of the Utah Lake drainage area may be classified as semiarid and temperate with conditions characterized by relatively low precipitation, low humidity, and high evaporation rate. Because of the climate sparse vegetation covers much of the land area. In the Heber-Francis area, native grasses occupy much of the valley floor with sagebrush growing on slopes and higher elevations. On the Wasatch Front areas, the dominant types of vegetation are sagebrush, greasewood, salt brush, and native grasses on the valleys with junipers at higher ridges. In general, the soils are characterized by low organic content and high calcium content. The climatic characteristics for representative stations are summarized in Table 2. The mountain valleys of Heber-Kamas area possess less favorable climate for crop production than the Wasatch Front areas due to lower temperatures and shorter frost-free growing season. (U.S. Dept. of Interior, 1964c, pp. 10-12).

Table 2 . Climatic characteristics[a] .

Station	Elevation ft.	Mean Annual Precip., In.	Mean Annual Temp., °F	Median frost free period[b] Dates	Median frost free period[b] Days
Utah Lake (Lehi)	4497	9.82	48.6	May 16 to Sep 24	132
Provo	4545	12.81	49.6	May 19 to Sep 22	127
Elberta	4690	10.22	50.6	May 14 to Oct 1	141
Spanish Fork PH	4711	16.79	52.0	May 1 to Oct 15	168
Lower American Fork PH	5044	16.45	52.2	Apr 30 to Oct 21	175
Heber	5593	15.05	44.5	Jun 19 to Sep 4	78
Snake Creek PH	5950	22.25	43.3	Jun 10 to Sep 4	87
Soldier Summit	7460	16.09	38.7	Jun 19 to Aug 13	56

[a] Hyatt, et al. 1968, Tables 5, 6, and 9.

[b] 50 percent probable chance that 32 °F will occur or after indicated dates.

Precipitation

The average annual precipitation, based upon the normal time period 1931-1960, varies from over 60 inches for the high peaks of the Traverse and Wasatch Mountains to less than 10 inches in the eastern Utah Lake and Goshen Valley areas (Utah State University, 1963, pp. 5-6).

In general, the precipitation decreases traversing west of the Wasatch Mountains. In most of Northern Utah Valley, Southern Utah Valley, and Northern Juab Valley, the normal annual precipitation varies from 12 to 16 inches. In Cedar Valley and Goshen Valley it varies from less than 10 to 12 inches. The high peaks of Mt. Timpanogos, Squaw Peak, and Spanish Fork Peak of the Wasatch Mountains receive from 30 to over 60 inches of precipitation, annually. The mountain valleys in the Heber-Kamas vicinity receive from 16 to 20 inches as shown by isohyetals of normal annual precipitation for the time period 1931-1960 (Hyatt, et al, 1968b).

Wind

The prevailing wind direction varies from southwest to northwest but in winter months is generally from the northwest. Violent windstorms in the area are almost unknown (U.S. Dept. of Interior, 1964c, p. 13).

Temperature

The temperature varies with altitude and latitude. There is about 3 degrees Fahrenheit (^{o}F) decrease in mean annual temperature for each 1000 feet increase in altitude and about 2^{o}F decrease for each one degree increase in latitude. Thus, at higher elevations, there is lower potential evapotranspiration. At lower elevations, due to the restricted available moisture, the actual evapotranspiration may not approach the potential evapotranspiration (Utah State Univ., 1963, pp. 5-7). In most of Northern Utah Valley, Southern Utah Valley, Goshen Valley, Northern Juab Valley, and Cedar Valley the mean annual temperature ranges from 45^{o} F to 50^{o} F based upon an isothermal map of mean annual temperature for the Utah Lake drainage area (Hyatt, et al. 1968b, p. 87). For the Wasatch Mountains the mean annual temperature ranges from 35^{o} F to 45^{o} F, the Heber-Kamas areas vary from 40^{o} F to 45^{o} F.

Agricultural Lands

Agriculture is the largest user of water resources within the Utah Lake drainage area. Irrigated agriculture constitutes 74 percent of all agricultural farmland. There is 162,150 acres in active use for irrigated crops and 57,508 acres for dry farm land as shown in Table 3. (Hyatt, et al. 1968a).

Representative irrigated crops are alfalfa pasture, grain, corn, sugar beets, and orchards. The largest amount of irrigated land is used for alfalfa and pasture; the combination constitutes 86,650 acres, or 53 percent of all active irrigated cropland.

Utah Valley contains 117,760 acres of irrigated cropland, or 73 percent of the total irrigated croplands in the Utah Lake drainage area. The Spanish Fork district (which encompasses Southern Utah Valley and Goshen Valley) contains 73,773 acres. This amounts to 63 percent of the Utah Valley, and 45 percent of the Utah Lake drainage area, croplands. Other areas containing irrigated crops used in this study are Heber-Frances (20,682 acres), Lehi-American Fork (20,492 acres), Provo (23,495 acres), Cedar Valley (3,328 acres), and Northern Juab Valley (12,391 acres). About 8.2 percent of the total land area in the Utah Lake drainage area is used for irrigated agriculture. The areas are summarized in Table 3.

Table 3. Agricultural lands[a].

Hydrologic Area[b]	No.[c]	Crop Area, acres[d]	Phreatophytes and Native Vegetation, Areas
(Heber-Kamas)	--	20,682	6,141
Francis (Kamas)	11	1,553	956
Heber	13	19,129	5,185
(Utah Valley)	18	117,760	40,500
(Lehi-Am. Frk.)	18a	20,492	1,937
(Provo)		23,495	8,080
(Spanish Fork)	18b-18c	73,773	17,554
Goshen Valley	18c	15,785	12,929
Cedar Valley	17	3,328	26
(Northern Juab Valley)	2	12,391	550
Other areas	--	7,989	62
Thistle	6	5,176	---
Round Valley	12	2,813	62
Utah Lake drainage	--	162,150	47,279

[a]Hyatt, et al. 1968a, Table 58.

[b]Areas in this study indicated by parentheses.

[c]Numbers are hydrologic subarea disignation.

[d]Includes classes A1 to A11 and A13 (see Appendix).

[e]Includes classes C1 to C4 (Very dense to light density growth).

Hydrology

The Utah Lake area is drained by two large rivers, the Provo and the Spanish Fork. Other principal streams are the American Fork River, Hobble Creek, Summit Creek, Payson Creek, Salt Creek, and Currant Creek.

Provo River

The Provo River, the largest of the Utah Lake tributaries, originates in the Western Uinta Mountains, flows through Kamas and Heber Valleys, down Provo Canyon and discharges into Utah Lake. The drainage area east of the crest of the Wasatch Mountains is about 650 square miles compared to about 25 square miles west of the crest.

The Provo River ordinarily furnished approximately twice the quantity of water as other rivers and streams north of the city of Provo (Thomas, 1953, pp. 66-67). Due principally to the contribution of the Provo River, the northern half of Utah Valley (north of the city of Provo), with less than 40 percent of the irrigated land, receives about 70 percent of the total inflow. The volume of natural inflow is variable with about one-half of the annual quantity occurring during periods of low irrigation demand (April through June) while only one-sixth occurs during periods of high demand (July through

September). (Hudson, 1962, pp. 73-74.) The river is essentially fully appropriated for irrigation, municipal, industrial, and power purposes (U.S. Dept. of Interior, 1964b, p. 263).

Spanish Fork River

The Spanish Fork River rises in the Wasatch Plateau west of Soldier Summit. The total drainage area is about 700 square miles, of which 675 square miles are on the east side of the Wasatch Summit. Similar to the Provo River, the unregulated runoff rate has a high peak during the spring months.

Streamflow regulation

Streamflow regulation in the form of reservoirs, interbasin transfers, and water allocation has occurred primarily along the Provo and Spanish Fork Rivers. The other streams contibute much less to the irrigation supply and have been subject to very little regulation.

Several examples of these modifications may be given. On the Provo River, 15 small reservoirs have been developed at the headwaters which contribute about 8000 acre-feet (AF) to irrigation annually. Deer Creek Reservoir, located at the western end of Heber Valley releases 96,700 acre-feet annually to the Provo River (U.S. Dept. of Interior, 1964b, p. 347a). On the Spanish Fork System, the Strawberry Reservoir, located in the Uinta Basin has a mean annual interbasin export to the Utah Lake drainage area of 60,800 acre-feet. The representative flows and principal water transfers in this area are presented in Table 4, which was obtained from a recent report by Hyatt, et al (1968b).

Diversions

Diversions from the Provo and Spanish Fork rivers are measured and published by the respective state appointed water commissioners. Diversions from the American Fork River and Hobble Creek are measured less frequently and are not published. Flows are usually measured by weirs at an accuracy within $\pm$ 15 percent. (Hudson, 1962, pp. 76-77).

The basis for measuring irrigation water in this area was compiled by Israelsen et al (1946, p. 41). Of 46 irrigation companies investigated, 22 measured volumes of water by approved engineering methods and recorded the same, 18 measured and divided water but did not record volumes, and five did not regularly measure water.

Table 4 . Mean annual flow for 1931-1960 time base adjusted to 1960 conditions[a].

River	Quantity, AF
Provo River	
near Kamas	34,300
Duchesne Tunnel	37,200*
Weber-Provo Diversion Canal	56,200*
at Hailstone	214,500
Ontario Tunnel	10,000 *
Dry Creek and Fort Creek	20,000
American Fork River	38,200
Battle Creek	4,000
Grove Creek	3,000
Rock Creek	8,000
Hobble Creek	29,500
Spanish Fork River	
at Thistle	56,400
Strawberry Tunnel	60,800[b]
at Castilla	151,400
Payson Creek	9,400
Summit Creek	8,900
Salt Creek near Nephi	19,300
Currant Creek below Mona Reservoir	15,000
Jordan River	261,000

[a]Hyatt, et al. 1968b.

[b]Transbasin import.

CHAPTER 3

EFFICIENCY

Definitions

In general, an irrigation system may be divided into three parts: the source (be it river or storage reservoir), the distribution system, and the application of water on the land. Each part of the system is subject to certain water losses which ultimately affect the quantity of water that may be beneficially used. These losses, as well as return flow components of the diverted water, are shown in Figure 4.

Within each part of the irrigation system an efficiency, the ratio between the usable outflow and the total inflow, may be determined. From a water resource point of view, these efficiency parameters are of importance because they are utilized in determining the quantities of water which are required for a given system and conversely, what system efficiency is required for a given quantity of water. There are other parameters which describe the performance of the application part of a system. These parameters indicate how the water is stored in the soil or distributed on the land. In this case, the root zone becomes the system and inflows, outflows, and changes in root zone storage must be considered. This is within the realm of agricultural engineering and has been described by Hall (1960, pp. 75, 76, 81) and Hansen (1960, pp. 55-57, 61, 64).

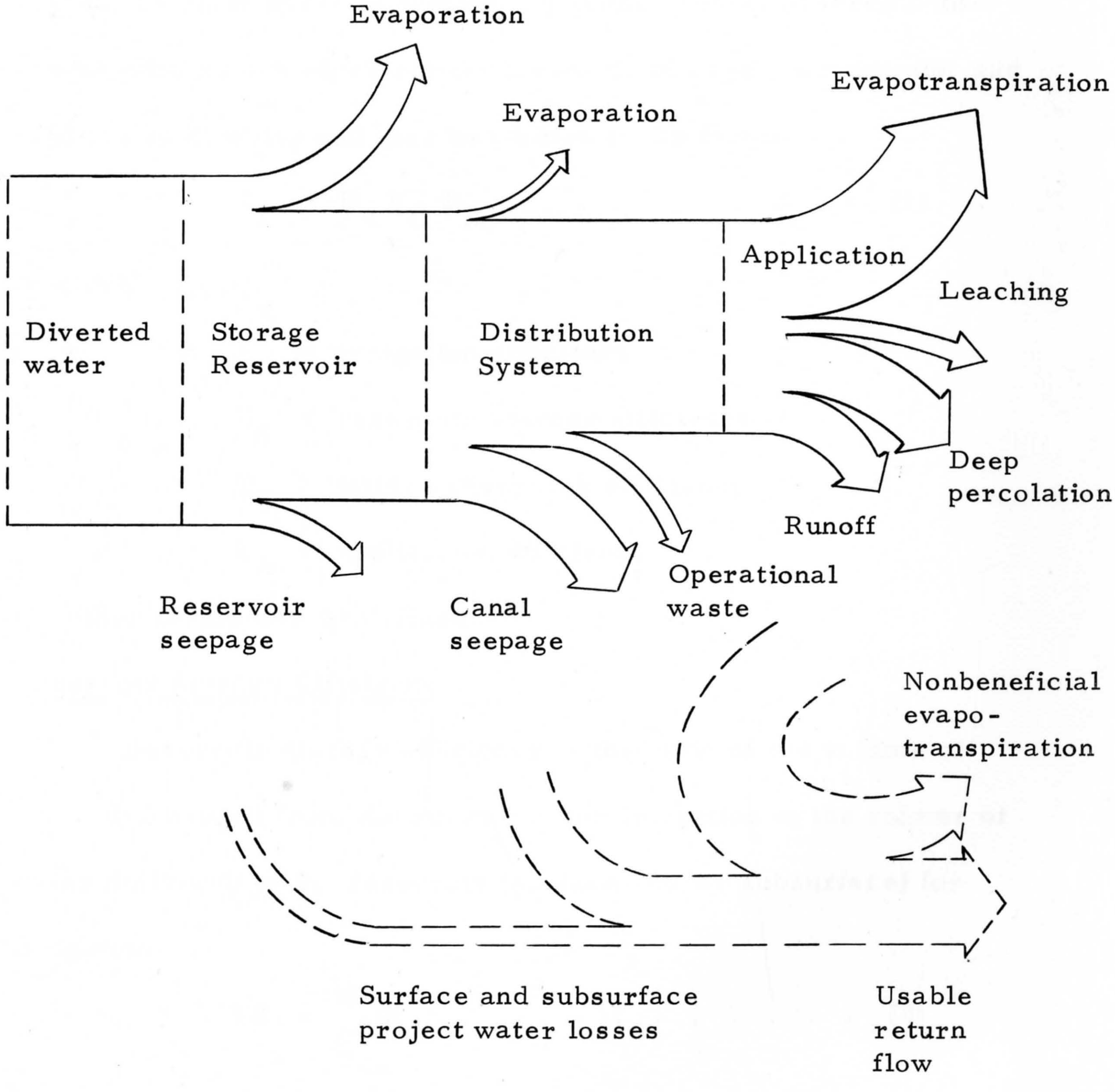

Figure 4. Irrigation water components (Jensen, 1967, p. 89).

Irrigation Efficiency

Irrigation efficiency is the ratio of the volume of irrigation water necessary for crop use to the total volume of water diverted, stored, or pumped for irrigation. It is the product of three component efficiencies which reflect losses in storage, conveyance, and application of water and may be written in the form:

$$E_I = E_S E_C E_A \quad \dots\dots\dots\dots \quad (1)$$

in which

E_I = irrigation efficiency

E_S = reservoir storage efficiency

E_C = water conveyance efficiency

E_A = application efficiency

the other terms will be defined.

Reservoir Storage Efficiency

Reservoir storage efficiency is the ratio of the volume of water discharged from the reservoir for irrigation to the volume of water delivered to the reservoir (surface and/or subsurface) for irrigation.

$$ES = \frac{W_{OR}}{W_{IR}} \quad \dots\dots\dots\dots \quad (2)$$

in which

ES = reservoir storage efficiency

W_{OR} = water discharged from the reservoir or net outflow

W_{IR} = water delivered to the reservoir or net inflow

Water Conveyance Efficiency

Water conveyance efficiency is the ratio of the volume of water delivered by a conveyance system to the volume of water diverted into the conveyance system at the supply source, or sources.

$$E_C = \frac{W_{OC}}{W_{IC}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

in which

E_C = water conveyance efficiency

W_{OC} = water delivered by the conveyance system

W_{IC} = water diverted into the conveyance system

Application efficiency

Application efficiency is the ratio of volume of water consumed by evapotranspiration, plus that necessary to leach the soil of salts, plus that change in water stored in the root zone minus, the effective precipitation in a specified area to, the total volume of water delivered to the area (Jensen, 1967, p. 86). This general definition can be described mathematically.

$$E_A = \frac{W_{ET} + W_L + \Delta W_S - W_P}{W_I} \quad . \; . \; . \; . \; . \quad (4)$$

in which

E_A = application efficiency

W_{ET} = volume of water consumed by evapotranspiration

W_L = volume of water necessary to leach the soil of salts

ΔW_S = change in volume of water stored in the root zone. It is negative if there is a decrease in water quantity; positive if there is an increase within the interval of time.

W_P = volume of effective rainfall

W_I = volume of diverted water

Other more traditional definitions are as follows:

$$E_A = \frac{W_{ET}}{W_I} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

or

$$E_A = \frac{\Delta W_S}{W_I} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

in which E_{ET}, E_I, W_A and ΔW_S are the same as defined previously. Under long term conditions, since W_{ET} is commonly estimated by field measurement of soil moisture, the two Equations (5 and 6) will be equivalent. For a short period of time, where steady-state does not exist, the quantity ΔW_S (or consumptive use between soil-moisture measurements) will have a significant effect (Jensen, 1967, p. 85). Water applied in excess of crop needs and stored in the root zone will be efficient in Equation 6 but will be inefficient in Equation 5. This discrepancy can only be determined by measurement techniques of W_{ET} other than by soil sampling. Since more refined techniques are usually financially infeasible, the discrepancy is usually undetermined. Finally, for experiments in which the precipitation (W_P) is accounted for, and in locations where leaching water (W_L) is insignificant, the three equations (4, 5, and 6) become comparable.

In common hydrologic practice, a coefficient (less than one) is applied to the actual precipitation volume to account for runoff percolation, and evaporation from the soil surface. In this study, a coefficient of unity is attached to the precipitation falling on the cropland. In arid areas, where the total growing season precipitation is light, the moisture level in the soil profile at the time of precipitation is usually such that almost all of it enters the soil profile and becomes available for consumptive use (U. S. Dept. of Agriculture, 1964, p. 24).

The volume of water necessary to leach the soil of salts is neglected in this study. Leaching requirements should be considered when drainage is restricted or when the available irrigation water is efficiently used, especially in saline and alkali soils. If application losses are high resulting in large quantities of water passing through the root zone, estimates of leaching have little practical significance. Also, in cases where water application efficiencies are highly variable or where a uniformity of water is not controlled, precision in the leaching requirement is unimportant (Richards, 1954, p. 38). In Utah Valley, application losses are high and application efficiencies are variable (Israelsen, et al., 1944) hence, W_L will be neglected.

The terminology for describing efficiency differs depending upon the point of measured input to the area under consideration. The commonly used efficiency terms are summarized in Table 5. In this study, project efficiency will be considered synonymous with irrigation efficiency.

Reservoir Storage and Water Conveyance Efficiency

This section will consider the present status of reservoir and water conveyance efficiency. There are four sources of storage and conveyance losses: seepage, operational waste, surface evaporation, and phreatophyte transpiration.

Seepage

Seepage, as used herein, is the quantity of water which is lost from a storage or conveyance facility or system through subsurface percolation. It does not include deep percolation from agricultural lands.

The limited amount of detailed data on seepage has been a hindering factor in the analysis of seepage phenomena and the determination of conveyance losses. Seepage rate measurement by means of present methods of pondage, seepage meter, and inflow-outflow are expensive. Seepage losses vary widely and may represent a considerable percentage of the flow. Houk summarized expected seepage losses in large projects varying from 15 to 45 percent of

Table 5. Supplemental efficiency terminology.[a]

Item	Location of Measurement	Designation	Symbol
1	Field	Field-irrigation efficiency	E_A
2	Farm headgate	Farm-irrigation efficiency	E_A
3	Reservoir or water course	Project-efficiency	E_I

[a]Blaney and Criddle, 1964, p. 30.

diversions for mostly unlined canals (Houk, 1951, p. 392). In long unlined canals, the losses may be as high as 50 percent (Israelsen, et al., 1946, p. 9). Seepage rates for the same type of canal linings in different areas may vary by a factor of 10 (U. S. Dept. of Interior, 1963, pp. 20-22).

Estimates conducted by the Bureau of Reclamation in the southern part of Utah Valley (in conjunction with the Central Utah Project) show that seepage losses in the major canals of that area vary from 4 to 14 percent of the diversions. These seepage losses were estimated by the use of the "Moritz Formula" (U. S. Dept. of Interior, 1964 b, p. 211):

$$S = 0.2C\sqrt{Q/V} \quad \ldots\ldots\ldots\ldots \quad (7)$$

in which

S = seepage loss in cubic feet per second per mile of canal

Q = discharge of canal, cfs

V = velocity of flow, in feet per second

C = depth of water lost through the wetted area in 24 hours

This formula appears to be purely empirical and nonstandardized. The Bureau references on water measurement and lining (U. S. Dept. of Interior, 1963; U. S. Dept. of Interior, 1967) do not include this formula. A list of conveyance losses and efficiencies is contained in Table 6. The "administrative loss" corresponds to operational loss. The conveyance

Table 6. Estimated conveyance efficiency for Southern Utah Valley and Northern Juab Valley[a].

Bureau of Reclamation project area	Conveyance loss in percent of diversion	Administrative loss, percent of diversion	Total losses, percent of diversion	Conveyance efficiency percent of diversion
Spanish Fork	12	5	17	83
Goosenest	4	0	4	96
Santaquin	6	0	6	94
Mona	10	0*	10	90
Nephi	14	0*	14	86
West Mona	10	0*	10	90
Elberta	14	0*	19	81

[a] U.S. Dept. of Interior, 1964b, p. 211.

*No administrative loss included because of terminal storage in Mona Reservoir.

losses vary from 4 to 14 percent, with the greatest losses being estimated for the Nephi and Elberta areas.

Unlined earth channels are more prevalent than any other type in irrigation systems. These have the advantage of low cost, but have the disadvantage of high seepage, maintenance, and control problems (U. S. Dept. of Agriculture, 1967, p. 3-48). The lining of canals or use of pipelines are possible solutions to heavy seepage losses as well as other conveyance problems. The ultimate change in water conveyance will be the use of pipelines. The limiting factor is the high initial cost which may be two to ten times as much as lined canals (Lauritzen, 1965).

Operational Waste

Operational waste consists of leakage at canal gates, intentional and unintentional release of water during conveyance, and mismeasurements. Reasonable waste are of the order of 5 percent of the diversions (Jensen, 1967, p. 92). On large projects, wastes may vary from 5 to 30 percent in areas of ample water supply and 1 to 10 percent in areas having a limited water supply (Houk, 1951, p. 392).

Evaporation

Evaporation from surface reservoirs is generally a very significant loss. In the 17 western states evaporation losses from large lakes and reservoirs amount to an estimated 14 million acre-feet (Stamm, 1964, p. 84). In Utah the estimated fresh water surface evaporation amounts to 850,000 acre-feet per year. In the Great Salt Lake Basin (not including the Great Salt Lake), the evaporation loss accounts for an estimated 620,000 acre-feet annually (Utah State Univ., 1963, p. 19-20). The mean summer (April to October) evaporation from shallow lakes and reservoirs in the Utah Lake drainage area is about 40 to 50 inches (Schwab, 1966, p. 77). In the Utah Lake drainage area, about 353,000 AF per year is evaporated from fresh water surfaces. For the Great Salt Lake Basin (not including the Great Salt Lake) principal streams and canals account for an estimated 24,800 acre-feet of evaporation annually. This is about 4 percent of the total estimated evaporation from all fresh water surfaces in the area. Estimates of evaporation in the Utah Lake drainage area are listed in Table 7.

Phreatophytes

Evapotranspiration from nonbeneficial plants results in significant consumptive losses in semi-arid regions. This factor is only indirectly considered in the demand calculations presented in Chapter 4. In the Utah Lake drainage area hydrologic inventory, the return flows from agricultural croplands are distributed over nonproductive lands. In addition, there are many nonbeneficial plants which occupy the beds and banks of canals and ditches, thereby depleting the water supply.

Table 7. Estimated evaporation from rivers and canals and reservoirs and phreatophyte evapotranspiration in the Utah Lake drainage area.[a]

Area or Subarea	Evaporation, AF/yr		Phreatophyte evapotranspiration
	River & Canal	Reservoir	AF/yr
Heber-Francis	1,200		11,900
Deer Creek Res.	-----	6,000	------
Utah Valley	-----		63,380
Utah Lake	-----	341,000	------
Lehi- Am. Frk.	-----		------
Provo	-----		------
Spanish Fork	-----		------
Northern Juab	-----		1,600
Mona Res.	-----	3,100	------
Utah Lake drainage	1,200	353,000	76,900

[a]Hyatt, et al., 1968b.

Robinson (1958, p. 1) has estimated that phreatophytes (desert plants which draw water directly from groundwater) cover 16 million acres in the 17 Western States and discharge as much as 25 million acre-feet of water into the atmosphere annually. A recent study in Malad Valley, Idaho, estimated that phreatophytes, densely covering 16,000 acres, consumed an estimated 37,200 acre-feet per year (2.3 AF/A). About 23,000 acre-feet is drawn from the capillary and phreatic zones. The quantities were based upon field estimations of area and density of plants species coupled with consumptive use rates for various plant species as obtained from the literature (Mower and Nace, 1957).

In Utah, a comprehensive determination of the extent and kinds of phreatophytes is yet to be made. Gross estimates have indicated that 0.75 to 1.50 million acres exist. Assuming an area of 1.2 million acres and an average net consumptive rate of 2 AF/A, this would result in an annual loss of 2.4 million acre-feet. Salvaging one-third of this quantity could potentially supply 200,000 acres or more, of agricultural land (Utah State Univ., 1963, p. 21). The quantity of water consumed by phreatophytes in the Utah Lake drainage area amounts to 76,900 acre-feet (Table 7) covering 47,279 acres. The areal distribution of phreatophytes is shown in Table 3 for the various areas.

Reservoir Storage Efficiency

The reservoir storage efficiencies depend on evaporation and base material (porous or cavernous rock and soil) characteristics. Average storage efficiencies are about 96 percent (U. S. Congress, 1960 c, p. 4). Due to high evaporation losses in the Great Basin, the efficiency in this area can be expected to vary considerably. The average storage efficiency of Deer Creek Reservoir is 99 percent, while the average storage efficiency at Mona Reservoir is 83 percent. Of significant importance to water resource development in Utah is the very poor storage efficiency of Utah Lake which is 44 percent (Hyatt, et al., 1968 b).

Water Conveyance Efficiency

In the entire U. S., the conveyance efficiency averages about 65 percent (Stamm, 1964, p. 88). According to Golze, Bureau of Reclamation records for 6 years of representative projects show average efficiencies for water delivered to farms (average area irrigated per project was 1.29 million acres) was 58 percent (Golze, 1946, p. 165).

In contrast, the Bureau of Reclamation estimates the conveyance efficiencies of main canals in Southern Utah Valley to vary from 81 to 96 percent (U. S. Dept. of Interior, 1964 b, p. 211). The figures were previously presented in Table 6.

In the literature survey, only one quantitative published figure on conveyance efficiency and seepage losses in the Utah Lake drainage area was encountered. In connection with canal lining studies, field investigation of seepage losses on the Provo Reservoir Canal was conducted along its 22 mile length. The total seepage loss was approximately 1 percent of the flow (about 200 cfs at the time of measurement) within a probable error of 2 to 3 percent. The limitations of measurement was such that although certain lands below the canal were waterlogged, the data did not indicate a loss (Lauritzen and Israelsen, 1949, pp. 29, 30, 37, 38).

Application Efficiency

Experiments

There were 16 application efficiency studies consulted. The three general types of experiments were controlled, marginal controlled, and field experiments. In the controlled experiments all irrigation facilities and techniques were controlled by the investigator. The field experiments were conducted on existing farmland. Marginal controlled experiments were conducted on experimental plots but statistical techniques were not applied in order to obtain unbiased estimates (see Steel and Torrie, 1960, pp. 88-89). The experiments also varied in the definition of application efficiency. The inclusion of consumptive use between measurements (ΔW_S) was significant in the study of Fuhriman (1951). A list of the application studies is shown in Table 8. Three studies were located in Utah (Bagley, 1965; Criddle, 1958; and Israelsen, 1944). Israelsen (1944) conducted the only experiment in the Utah Lake drainage area.

The results may be sub-divided according to type and the method of irrigation. The methods of irrigation include sprinkler and surface (check flood, burrow, basin, etc.). The results are summarized in Table 9. The resulting "averages" are to be taken as guides rather than absolute values. Although the efficiency values have been divided into categories, the great differences in experimental procedures and environmental conditions make comparison difficult. Under controlled conditions, the surface irrigation methods attain efficiencies exceeding 70 percent, while sprinkler irrigation methods exceed 80 percent efficiency. Sprinkler methods may be expected to yield higher efficiencies. The reasons are principally due to less runoff and less skill required by the operator in controlling water quantity and direction of flow than in surface irrigation methods. Under field conditions, the efficiency for surface methods drop to about 45 percent. This decrease of 35 percent between controlled and field conditions in surface irrigation methods may be due to farm-irrigation management practices.

The application efficiency studies were written from an agricultural engineering viewpoint. The emphasis was placed on experimental

Table 8. List of application efficiency studies

Study	Type	Efficiency Equation
Bagley (1965)	Field	6
Beckett (1930)	Field	6
Blaney (1942) in Cannell (1962)	Field	6
Criddle (1958)	Field	5
Currie (1959) in Hydson (1962)	Field	4
Erie (1954)	Marginal controlled	6
Fuhriman (1951)	Field	4
Israelsen (1944)	Field	6
Kruse (1962)	Controlled	4
Marsh (1956)	Field	6
Meyer (1956)	Field	6
Pair (1962) & Myers (n. d.)	Marginal controlled	6
Schoenleber (1943)	Marginal controlled	6
Somerhalder (1958)	Controlled	6
Stork (1959)	Marginal controlled	6
Swarner (1963)	Field	-

Table 9. Summary of application efficiency studies.

Type	Efficiency Equation	Method of Irrigation	Number of Averages	Application Efficiency, Percent
Field	4	Surface	2	51
	5	Surface	1	44
	6	Surface	13[b]	46
		Sprinkler	1[a]	72
Marginal controlled	6	Surface	8	57
		Sprinkler	4[c]	57
Controlled	4	Surface	1	72
		Sprinkler	1	84
	6	Surface	1	74
		Sprinkler	1	82

[a] The sprinkler irrigation results reported by Beckett (1930) are of doubtful value due to the advance of sprinkler equipment. Only the results by Bagley (1956), for winds less than 5 mph, is included.

[b] Includes Fuhriman's (1951) uncorrected value.

[c] Includes Schoenleber's (1943) overhead spray and rotary spray methods.

methodology and the immediate effects of water conservation in relation to the farm. There was no information on the practical consequences of obtaining high application efficiency throughout a large basin.

Utah Valley Study

Israelsen's study (1944) shows the practical field efficiencies which are commonly obtained in the Utah Lake drainage area. The mean efficiency value for Utah County areas (including three soil types) is about 39 percent, but there was a great deal of variation of values.

The method of determining the efficiency follows:

(1) The soil moisture content before irrigation was determined. A representative soil sample was taken from each foot of the core sample.

(2) Water was applied. The flow in cfs and time of irrigation in hours was measured.

(3) Soil samples were collected again after one or two days for moisture content determination.

(4) Weight of dry soil in root zone was determined.

(5) Area of plot covered was measured.

(6) Crops were noted and root zone depths were assumed.

(7) The efficiency was calculated by Equation (6) as discussed previously. (Israelsen, et. al., 1944, p. 13).

The farms investigated were classified according to soil type and drainage characteristics. In Utah County there were three classes:

Class I--gravelly to sandy loam, shallow coarse textured topsoil underlain with gravel and well drained, ClassII--medium loam and fair to good drainage, and Class III--fine textured soils and impaired drainage.

For Class I land, the range of efficiency was 6 to 92 percent with an average of 38 percent. The dominant factors contributing to low application efficiency in 30 tests (77 percent of total) which were below 50 percent were excessive application of water (14) and uneven distribution of water (7). In Class II land, the range of efficiency was 8 to 93 percent with an average of 44 percent. The major factors contributing to efficiencies lower than 50 percent in 60 tests (67 percent) were uneven water distribution (20), high moisture content before irrigation (15) and excessive depth of water applied (13). For Class III land, the range of efficiency was 9 to 85 percent with an average of 34 percent. In these lands, the dominant factors contributing to efficiencies less than 50 percent (12 tests or 75 percent) were excessive depths of water, extensive water spreading, and high moisture content before irrigation.

The application efficiencies of the eleven Utah County farms were not representative because of the widely varying irrigation methods and practices although the soil type and irrigation conditions were representative of the area. A relationship of the water application efficiency and the depth of applied water was determined (Figure 5). For depths exceeding 5 inches, the efficiency was less than 50 percent.

Israelsen concludes that the factors which are controllable by the irrigator contribute largely to low water application efficiencies:

(1) Preparation of land for irrigation.
The irrigator commonly runs water down steep slopes of 4 percent, or higher, resulting in excessive erosion, insufficient percolation and large runoff.

(2) Methods of water application.
The irrigator commonly uses flooding techniques which may be obsolete and not suitable for the given conditions.

(3) Time rate of water application.
On some farms, the application rate was so slow that much water is lost into the subsoil before reaching the end of the field.

(4) Surface runoff losses.
Excessive water application resulted in large runoff losses and lack of water control by the irrigator.

(5) Soil moisture content before irrigation.
Irrigators frequently applied water when the root zone was near field capacity. This caused excessive deep percolation.

(6) Volume of water applied at each irrigation.
Farmers applied more water than actually needed.

(7) Available water supply.
Farmers tend to over-apply water in times of plentiful supply which reduces efficiency.

(8) Personal attention to water distribution.
Irrigators commonly leave the irrigation to inexperienced help or entirely neglect irrigation. (Israelsen, et. al., 1944, p. 15).

Estimates

There are many estimates of application efficiencies made at

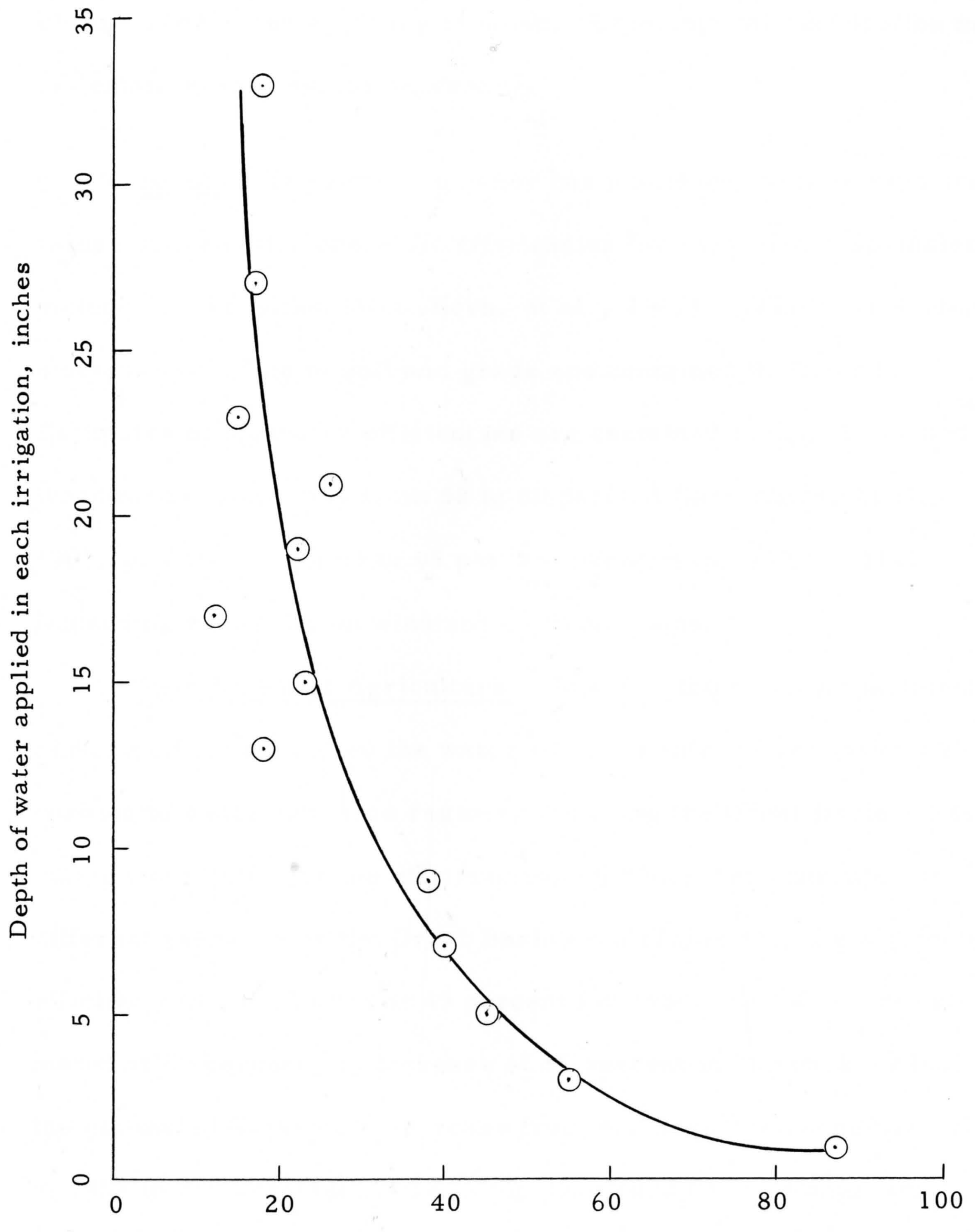

Figure 5. Relation of water application efficiency to irrigation water depths for Utah County (Israelsen, et al., 1944, p. 53).

various times and places. They may be conditionally accepted provided their limited accuracy is noted. Experimental verification may, in certain situations, be necessary.

Ames. The Ames Company has published average expected values of irrigation operation efficiencies for surface and sprinkler methods of irrigation (McCulloch, et al., 1967). Values for surface methods according to soil and grade are contained in Table 10. Estimates of sprinkler efficiencies are contained in both Ames and Woodward. They vary from 58 to 80 percent (McCulloch, et al., 1967, p. SMF-3) and 65 to 95 percent (Woodward 1959, p. 111) Depending primarily on wind and soil conditions.

Department of Agriculture. In 1960, the U. S. Department of Agriculture estimated the water requirements for irrigation according to water resource regions, including the Great Basin. Estimates were given for the efficiencies and necessary quantities at different years. For the Great Basin area (Table 11), the application efficiency was estimated at 45 percent for 1954; in 2000 it was estimated at 60 percent, an increase of 15 percent in 46 years. Also, the estimated water duty decrease from 4.2 acre-feet/acre (AF/A) in 1954 to 2.9 acre-feet/acre in the year 2000 (U. S. Congress, 1960 b, p. 66-68).

Bureau of Reclamation. The Bureau of Reclamation estimated application and conveyance losses on the farm in connection with the

Table 10. Estimated application efficiencies for surface irrigation methods[a].

Site condition	Borders	Furrows or Corrugations	Flooding with Grade Ditches	Basins
1. Sandy soils				
(a) Well graded to optimum grade	60	40-50	45	70
(b) Insufficient grade	40-50	35	30	--
(c) Rolling or steep	--	20-30	20	--
2. Medium textures--deep				
(a) Well graded to optimum grade	70-75	65	55	70
(b) Insufficient grade	50-60	55	45	--
(c) Rolling or steep	--	35	35	--
3. Medium textures shallow				
(a) Well graded to optimum grade	65	50	45	60
(b) Insufficient grade	40-50	35	35	--
(c) Rolling or steep	--	30	30	--
4. Heavy Soils				
(a) Well graded to optimum grade	60	65	50	60
(b) Insufficient grade	40-50	55	45	--
(c) Rolling or steep	--	35-45	30	--

[a]McCulloch, 1967, p. SCR-3.

Table 11. Annual water requirements for the Great Basin water resource region.[a]

Year	Required on Farm			Req'd for Diversion		Est. Recovery of Losses, Percent	Total Irrigation Requirement	
	Net required by Plant, ac-in/a	Application Efficiency Percent	Total Req'd ac-in/a	Storage & Delivery Efficiency, Percent	Total Req'd ac-in/a		ac-in/a	AF/A
1954	21	45	47	55	85	55	50	4.2
1980	21	55	38	60	63	55	40	3.3
2000	21	60	35	65	53	55	35	2.9
Net change 1954-1980	0	+15	-12	+10	-32	0	-15	-1.3

[a]U.S. Congress, 1960 b, p. 66-68, Dept. of Agri. estimates.

Central Utah Project. The efficiencies varied slightly according to land classification, of which one component was soil type (Table 12). The Wasatch Front and Heber-Kamas areas differed from each other in some of the specifications for land classification (i.e., depth to solid rack, uniform slopes, length of irrigation runs) but the soil type and the estimated water losses for the corresponding classes remained constant.

The application efficiencies estimated by the Bureau of Reclamation are dependent upon the relative percentage of the land class. The percent of land class is multiplied by the farm efficiency for that class in order to obtain the weighted farm efficiency. The sum of the weighted farm efficiency for all classes yields the total farm efficiency for the area. These farm efficiencies are summarized in Table 13. The range of 51 to 59 percent appears high in relation to Israelsen's study (1944) and other field studies.

Improvement of Application Efficiency

The principal contributors to application efficiency are the factors of irrigation system design and irrigation system operation (Berg, 1960; Finkel, 1960; Houk, 1951). Ultimately, the individual irrigator's responsibility will have the greatest affect on water application efficiency, particularly when surface irrigation methods are utilized. Basic points are:

Table 12. Farm irrigation losses and efficiencies for land classes in the Wasatch Front and Heber-Kamas areas.[a]

Class	Soil Type	Farm Ditch Seepage, % of Diversion	Surface Waste, % of diversion	Deep Perco-lation, % of Diversion	Farm Efficiency, % of Diversion
1	sandy loam to friable clay loam	7-8	15-17	15-17	60
2	loamy sand to very permeable clay	7-10	15-25	15-20	55
3	loamy sand to permeable clay	7-12	20-30	15-25	50

[a] U. S. Dept. of Interior, 1960 c, pp. 26, 27; U. S. Dept. of Interior, 1960 b, pp. 210, 319.

Table 13. Farm efficiencies for the Central Utah Project.[a]

Area[b]	Total Farm Efficiency, percent
Heber-Francis	51-52
(Francis)	(52)
(Heber)	(51)
(Provo Bay)	(59)
Spanish Fork	56
(Gooseneck)	(55)
(Santaquin)	(56)
Goshen Valley	56
(Mosida)	(56)
(Elberta)	(56)
Northern Juab	55-56
(Mona)	(56)
(West Mona)	(55)
(Nephi)	(55)

[a] U. S. Dept. of Interior, 1964 b, pp. 210, 319.

[b] U. S. Bureau of Reclamation project areas in parentheses.

(1) Determination of water need.
The irrigator must be aware that moisture is being depleted from the root zone. He should know the proper time to irrigate. Both the soil character and water content is integrated in the measurement of matric potential by tensiometers or resistance blocks. (Taylor, 1965, p. 433)

(2) Control of quantity.
The irrigator must be certain of the quantity of water received by means of flow measuring devices such as weirs and flumes. Upon application, he should control the quantity applied through adequate stream sizes or nozzle openings.

(3) Uniformity of application.
The greater the degree of uniformity, the more efficient will be water use with consequent benefits to both crop and soil. If topography does not permit increased uniformity, then leveling must be done or more suitable irrigation methods (such as sprinkling) must be employed.

(4) Personal attention.
Without a reasonable amount of personal attention to the quantity and uniformity of application, a high degree of efficiency cannot be expected. (Berg, 1960, p. 71-82).

The latitude in individual action with respect to the above four factors prevents specific quantitative assessment of their affect on efficient water use. The generalization is that the difference between the application efficiencies obtained in the field and those obtained by investigators under controlled conditions reflect the degree of possible improvement. In addition, it is clear from the figures given, that among the three components of irrigation efficiency (reservoir, conveyance, and application) the application efficiency is highly variable, difficult to estimate, and the most influential in the resultant irrigation efficiency.

Estimated Efficiencies for Study Area

The previous discussion of efficiency shows the limited amount of data that exists in general and particularly in the Utah Lake drainage area. The dearth of data is largely due to the expense involved in determining the seepage losses and soil moisture content. In the absence of more concrete and current data on conveyance and application efficiencies, the present figures for the Utah Lake drainage area are subject to the disadvantages of estimation. The present efficiencies of the Utah Lake drainage area were obtained from the hydrologic inventory conducted by the Utah Water Research Laboratory. The conveyance and application efficiencies were estimated by considering primarily the U. S. Bureau of Reclamation figures (contained in Tables 8 and 13 but supplemented by the other information previously presented).

In the Utah Valley, a conveyance and application efficiency was individually assigned to the various canal company service areas (see the Appendix). The estimated efficiencies for the Lehi-American Fork, Provo, and Spanish Fork districts were calculated by weighting the conveyance and application efficiencies of the canal company service areas according to their diversion quantities, adding the products, and then dividing the sum by the total diversion for the district. The product of the application and conveyance efficiencies

Table 14. Estimated efficiencies for Utah Lake drainage areas.[a]

Area or subarea	Conveyance Efficiency E_C, %	Application Efficiency E_A, %	Irrigation Efficiency E_I, %
Heber-Kamas	69	47	32
Utah Valley	80	46	37
Lehi-American Fork	80	41	32
Provo	78	45	35
Spanish Fork	82	51	42
Northern Juab	70	50	35
Utah Lake drainage	78	46	36

[a] Hyatt, et al., 1968 b, calculated.

results in irrigation efficiency. The Heber, Kamas, and Northern Juab subareas were assigned overall application and conveyance efficiencies. The Heber-Kamas subarea, Utah Valley subarea, and the Utah Lake drainage area irrigation efficiencies were determined similarly to the districts except the component areas were districts and subareas instead of canal company service areas. The irrigation efficiencies range from 32 percent for Heber-Kamas to 42 percent for Spanish Fork.

The average conceivable range of conveyance and application efficiency that might be applied to the Utah Lake drainage area is shown in Table 15. The figures were obtained by considering the information previously presented.

Table 15. Estimated range of losses and efficiencies of conveyance and application.

	Loss, Percent of Diversion		Efficiency, Percent
Conveyance	Seepage	Operational waste	
Closed pipeline	0	0-5	95-100
Exposed hard surfaced or buried membrane linings	5-15	3-8	77-92
Earth linings	10-20	5-10	70-85
Unlined	15-45	5-15	40-80
Application	Deep Percolation	Surface Waste	
Sprinkler	15-30	5-20	50-80
Surface methods	20-60	10-40	10-70

CHAPTER 4

IRRIGATION DEMAND

Definitions

Irrigation demand is the quantity of water necessary for agricultural operations considering the characteristics of the components of an irrigation system (see Figure 4). In this paper, demand is the absolute quantity of water at the supply source (or diversion point) necessary to satisfy crop water requirements, taking into account irrigation efficiency. Monthly demand (DEM) is the total monthly crop potential consumptive use (SPCU) divided by irrigation efficiency (EI).

The present mean diversion quantities will, when combined with demand, generally result in either a surplus or a deficit of water at the diversion point. The monthly surplus (SR) and deficit (DF) considers the mean diversion, root zone storage, and precipitation. In this study, a surplus is a negative quantity while a deficit is a positive quantity.

The demand, surplus, and deficit may also be considered on an annual time basin. The annual demand (DEMA) is the addition of all monthly demands (DEM). The annual surplus (SRA) and deficit (DFA) is the sum of all monthly surpluses (SR) and deficits (DF). The annual quantity may be positive (deficit) although in certain months negative (surplus) quantities may exist.

Finally, an annual quantity which results in a surplus or deficit that does not consider the effect of precipitation and root zone storage may be determined. The annual surplus (SRAZ) and deficit (DFAZ) is the annual demand (DEMA) minus the annual sum of mean monthly canal diversions (CD).

Computational Procedure

A computer program was used to obtain the basic data of potential consumptive use (SPCU) and canal diversion (CD) on a mean monthly and mean annual basis. The use of the computer was helpful in the analysis of the Utah Valley subarea because large amounts of data was involved.

The Utah Lake drainage area was divided into subareas and districts for more effective analysis:

- Heber-Kamas subareas
- Utah Valley subarea
  - Lehi-American Fork district
  - Provo district
  - Spanish Fork district
- Northern Juab Valley subarea

In the Utah Valley subarea, there were 25 service areas of irrigation companies considered. Within each irrigation company area, monthly diversion records and crop acreages were available. The districts are composed of groups of irrigation companies combined according to the source of diversion. Specific data is listed in the Appendix.

The Heber and Kamas subareas were combined since they are both located on the upper reaches of the Provo River. Although irrigation companies exist in these subareas, the large quantities of return and seepage flows did not justify an additative process of individual company diversions. Hence, one set of diversion and potential consumptive use was used for each subarea. The Northern Juab Valley subarea was treated as a unit area for diversion and consumptive use quantities.

The period of record of the data was largely in the interval 1945 to 1965 (21 years). In certain areas, the years of record was shorter or longer (e.g., Northern Juab Valley, 30 years).

The canal diversions (CD) for the Provo and Spanish Fork Rivers were obtained from river commissioner reports. On the other streams, data was secured from records of the U.S. Geological Survey, U.S. Bureau of Reclamation, and Utah State Engineer's Office.

The consumptive use was estimated by the Blaney-Criddle method:

$$u = k\ f$$

$$U = \Sigma\ k\ f$$

in which u = monthly consumptive use of crop, inches

U = annual consumptive use, inches

k = monthly empirical consumptive use crop coefficient (which varies according to crop)

f = monthly consumptive use factor

The factor f is determined by the equation:

$$f = \frac{tp}{100}$$

in which t = mean monthly air temperature in degrees Fahrenheit

p = monthly percentage of daylight hours in the year

The factor k is determined by the modification developed by the Soil Conservation Service (U.S. Dept. of Agriculture, 1964):

$$k = k_t k_c$$

in which k_t = climatic coefficient related to the mean air temperature, t

k_c = coefficient reflecting the growth stage or crop

The coefficient k_t is computed by the equation:

$$k_t = 0.0173t - 0.314$$

The coefficient k_c is determined by the use of curves for specific crops.

The soil moisture capacity (SMC) was determined by the conjunctive use of soil maps developed by the U.S. Bureau of Reclamation and estimates of root depths for each crop. The two factors combined resulted in the maximum volume of water that may be stored in the root zone.

After the potential consumptive use and diversions on a mean monthly and annual basin was determined, the demands, surpluses and deficits were computed. In the calculations for surpluses and deficits considering root zone capacity, there were eleven general assumptions:

(1) The soil moisture capacity is maintained constant. This disregards the fact that certain crops are not consumptive users throughout the growing season.

(2) The soil moisture content at the conclusion of the growing season is zero. The winter precipitation then builds the soil moisture content up to essentially capacity level.

(3) The crop pattern has remained constant for the years of record.

(4) The volume of water utilized by crops for evapotranspiration is determined by a modified form of the Blaney-Criddle method.

(5) The potential consumptive use is derived only for agricultural crops serviced by water originating from surface flows. Non-agricultural lands and those croplands served by pumped groundwater and waste waters are neglected.

(6) The full mean precipitation is used as effective precipitation.

(7) Mean values of quantities are used throughout.

(8) The excess volume of water lost through deep percolation, runoff, and seepage losses and through inefficiency is not utilized again in return flows over the cropland.

(9) Effects of surface storage by canal companies and individual farmers are neglected.

(10) The irrigation efficiency remains constant throughout the growing season.

(11) The water is distributed uniformly within the area considered. (U.S. Dept. of Interior, Bureau of Reclamation, 1964a, p. 191)

The monthly surplus (SR) and deficit(DF) are basically calculated by the modification of the equation as described for the determination of application efficiency (Equation 4):

$$EI = \frac{SPCU - PCL + (SMC - ASMS)}{CD + DF} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (9)$$

in which EI = irrigation efficiency

SPCU = volume of water potentially consumed by evapotranspiration

SMC = soil moisture capacity

ASMS = accumulated soil moisture supply

PCL = volume of effective precipitation

(SMC - ASMS) = volume of storage available in root zone

CD = volume of water diverted

DF = volume of deficit

There are several changes in the components of Equation 4. The volume of water potentially consumed by evapotranspiration (SPCU) replaces the actual estimation of evapotranspiration (W_{ET}). The lack of direct data, such as soil moisture samples and energe balance quantities, required the adoption of this method. The storage available in the root zone (SMC - ASMS) supplants the change in volume stored in the root zone (ΔW_S). The monthly deficit (DF), or surplus (SR) if negative, is added to the denominator. Finally, irrigation efficiency replaces application efficiency since the surpluses or deficits of a large area are considered. The deficit (DF) or surplus (SR) may be equated:

$$DF\ [\text{or } SR] = \left[\frac{SPCU - PCL + (SMC - ASMS)}{EI}\right] - CD \quad (10)$$

When the quantity within the brackets on the right side of the equation exceeds the diversion (CD), then a deficit results; when it is less than the diversion, a surplus results.

Basically, there are two situations which guide the computation:

(1) The quantity [(SPCU - PCL)/EI] is less than the accumulated soil moisture supply (ASMS). The diversion (CD) is applied to fill the soil storage [(SMC-ASMS)/EI]. Any excess water greater than the soil moisture capacity (SMC) is recorded as a surplus (SR).

(2) The quantity [(SPCU-PCL)/EI] is greater than the accumulated soil moisture supply (ASMS). The applied diversion (CD) then may be greater than or less than the potential consumptive use deficit, PCUD or [(SPCU - PCL - ASMS)/EI]. If the canal diversion (CD) is less than the potential consumptive use deficit (PCUD), the accumulated soil moisture supply (ASMS) is reduced to zero and a deficit (DF) is recorded.

The nomenclature for the monthly surplus and deficit is summarized in Table 16 and the calculation process is shown in Figure 6.

Table 16 . Nomenclature for monthly surplus and deficits.

AC1	=	Crop area, percent of total crop area
AGSC	=	Crop growth stage coefficient
ASMS	=	Accumulated soil moisture supply, AF
ARZS	=	Adjusted water supply to root zone, AF
CC	=	Precipitation adjustment coefficient
CD	=	Canal diversion, AF
CT	=	Temperature adjustment coefficient
DF	=	Monthly deficit, AF
DEM	=	Monthly demand, AF
EI	=	Irrigation efficiency, fraction
F	=	Blaney-Criddle consumptive use factor
GSC	=	Crop area including growth stage coefficient, AF
I	=	Subscript denoting month
PCL	=	Adjusted precipitation on cropland, AF
PCUD	=	Potential consumptive use deficit, AF
PDH	=	Percent daylight hours
PREC	=	Mean monthly precipitation, inches
RZS	=	Diverted water to root zone, AF
SGSC	=	Growth stage coefficient
SMC	=	Soil moisture capacity, AF
SMS	=	Soil moisture supply, AF
SPCU	=	Total monthly potential consumptive use, AF
SR	=	Monthly surplus, AF
STR	=	Storage in root zone available, AF
TAVE	=	Adjusted monthly temperature, F
TEMP	=	Monthly temperature, F

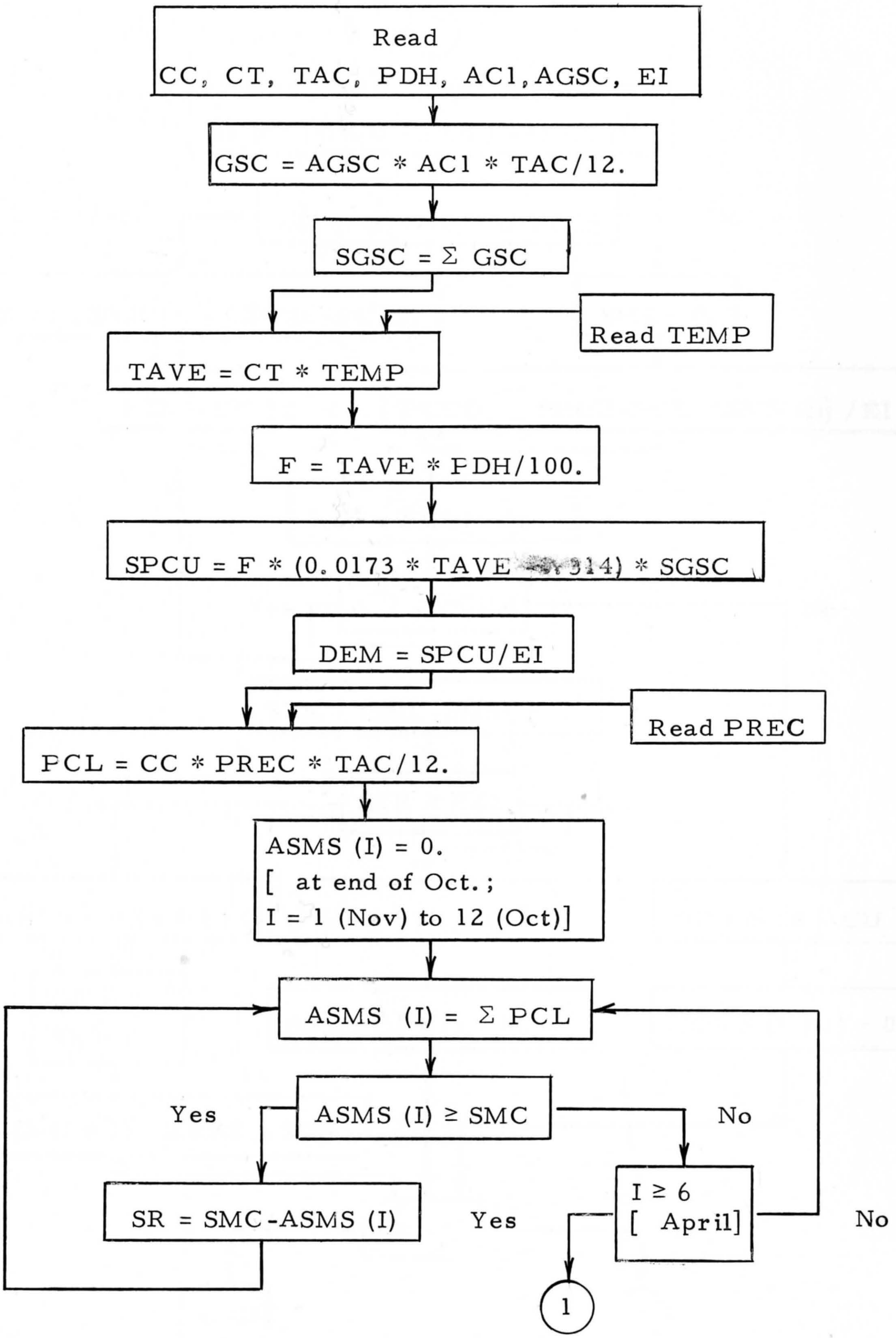

Figure 6. Block diagram for monthly surplus and deficit.

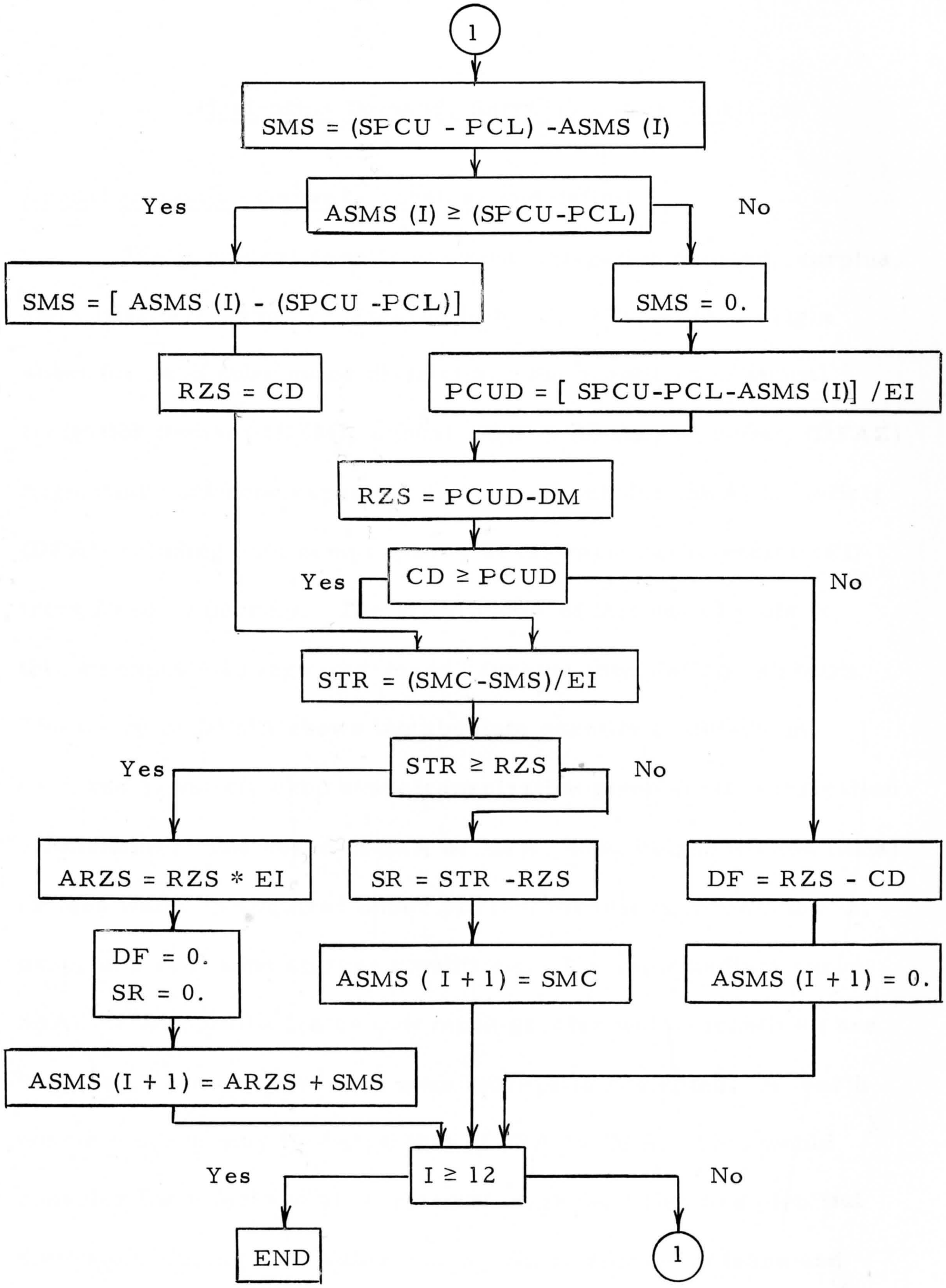

Figure 6. Continued.

Irrigation Demand, Surplus, and Deficit

Annual irrigation demand, surplus, and deficit

The graphical results of annual irrigation demand, surplus, and deficit are shown on Figures 16 to 23. Plotted on a single sheet for each subarea or district are the quantities of annual irrigation demand (DEM), annual surplus (SRAZ) or deficit (DFAZ) neglecting root zone capacity, and annual surplus (SRA) or deficit (DFA) including root zone capacity at irrigation efficiencies (EI) from 20 to 70 percent. The significance of this set of plots is that an expected range of demand, surplus, and deficit is shown. The curve of DEMA shows the absolute quantity of diversion required to satisfy crop evapotranspiration given certain irrigation efficiencies. The curve of SRA or DFA shows how much additional or less water is required under present diversion, precipitation, crop, and root zone storage conditions. The intermediate curve SRAZ or DFAZ illustrates how much greater water quantities are required if the effect of root zone storage is neglected. A fourth possible curve may lie below that of SRA or DFA. This would consider the effects of all surface storage facilities and plentiful diversions during high water years. Since storage release and management is beyond the scope of this study, this level has been omitted.

In the Provo district, the curve (Fig. 19) for the surplus or deficit excluding root zone storage (SRAZ, DFAZ) is close to that of the surplus or deficit including root zone storage (SRA, DFA) for surpluses (SRAZ). This indicates that for surpluses the root zone storage has little effect since it has limited capacity. Hence, the net effect of root zone storage on surpluses will be small if it remains near capacity level. Another notable feature is that the SRA-DFA curve is discontinuous between irrigation efficiencies of 23 to 28 percent. This will be explained in connection with the sum of monthly surpluses and deficits curves (Figure 34).

The rate of change from lower to higher efficiencies decreases. A small increase in efficiency at low efficiency decreases the surplus or deficit (SRA, DFA) much more than at high efficiency.

A discrepancy exists between the values of the annual surplus or deficit (SRA, DFA) for the larger areas and the sum of the subareas and districts at a given irrigation efficiency. The discrepancy here is defined as the surplus or deficit of the larger areas minus the surplus or deficit of the sum of its component areas. For example, the sum of the annual surplus or deficit (SRA, DFA) of the Lehi-American Fork plus Provo plus Spanish Fork districts will not, in general, equal the annual surplus or deficit for Utah Valley. The relationship between the discrepancy and irrigation efficiency is shown on Figure 23. This discrepancy may be explained in terms of root zone storage. At low efficiency, the surplus or deficit of the subareas approaches that of the larger area because the root zone storages have been nearly depleted for the crop months. This means that the root zones of both the area and its subareas are nearly depleted. In the middle efficiencies, the deficits of the subareas is greater than that of the larger area. This is because some individual areas may have depleted root zones which causes high deficits while other areas have essentially no deficit. Finally at high efficiencies, the deficit of the subareas is less than that of the larger area. The reason for this is that some individual areas have large surpluses while other areas have small deficits. The indication is that an analysis of a larger area tends to show much less fluctuation than the component areas since an equitable distribution of water within the time period is assumed. Superposition of the surpluses or deficits for the individual areas is not permissible to obtain the surplus or deficit of the larger area.

In view of the discrepancy, a more practical surplus or deficit is obtained by the summation of the values of the component areas. The reason is the water over a large area such as Utah Valley will never be applied as uniformly as assumed in the calculations. The greater variability in the effect of root zone storage is reflected by the sum of the subarea surpluses or deficits. In the subsequent references, the sum of SRA or DFA for the Utah Valley subarea and the Utah Lake drainage area components will be designated as SRA or DFA. The computed surplus or deficit for the large areas will be designated as SRAS or DFAS, respectively.

Monthly surplus or deficit

The monthly surplus (SR) or deficit (DF) including root zone storage, diversion, and precipitation plotted against irrigation efficiency in the range 10 to 80 percent are shown in Figures 24 to 30. For each subarea or district, the months are separated into two sections in order to avoid confusion.

The curves are discontinuous at zero net demand (zero surplus or zero deficit). This may be explained by a specific example. In the Lehi-American Fork district, for the month of June and at 10 percent irrigation efficiency, there is a deficit of about 24,000 acre-feet. The combined root zone storage and diversion is not sufficient to meet the potential consumptive use. Increasing the efficiency to about 15 percent causes the deficit to become zero. From about 15 percent to 43 percent irrigation efficiency, the root zone is filling up to capacity level, resulting in zero deficit. Beyond 43 percent, the additional water is in excess of the quantity necessary for root zone storage and crop evapotranspiration and is recorded as surplus.

In all areas, as expected, the highest deficit is exerted during the month of July. The early crop months of April and May show surpluses at higher irrigation efficiencies. The remaining months exhibit deficits at low efficiencies which taper off to zero at higher efficiencies. At any given efficiency, the sum of the monthly surpluses (SR) or deficits (DF) will yield the annual surplus (SRA) or deficit (DFA) which were discussed previously.

<u>Annual sum of surpluses and deficits</u>

The annual surplus (SRA) or deficit (DFA), including root zone storage, diversion, and precipitation, does not show whether there is a maldistribution of water during the season at a given irrigation efficiency; there may be a zero annual surplus, but deficits (DF) may exist at midseason, while surpluses (SR) may exist at the beginning of the crop season. The curves of Figures 31 to 37 show the annual sum of both the monthly surpluse (SR) and deficits (DF). These curves may be compared with the annual surplus (SRA) and deficit (DFA) in Figures 16 to 22 which were previously discussed. For example, for the Heber-Kamas subareas, at 35 percent irrigation efficiency, there is an annual surplus (SRA) of 5000 acre-feet (Figure 16); but there exists a total deficit (Σ DF) of 8000 acre-feet and a total surplus (Σ SR) of 13,000 acre-feet.

In the Utah Valley subarea and the Utah Lake drainage area curves (Figures 32 and 37, respectively), there are two sets of graphs. In the solid-line curve, the assumption is that the water is uniformly distributed over the entire area; in the dashed-line curve the result is the sum of the surpluses or deficits of the component areas. As expected, the sum of the subarea quantities show greater surpluses (Σ SR) and deficits (Σ DF). In the subsequent references, the results of the component subareas will be referred to whenever quantities of these curves are cited.

In the graph of the Provo district (Figure 34), the sum of the deficits (Σ DF) and the sum of the surpluses (Σ SR) do not overlap over a common efficiency range. Thus, these curves are equivalent to a single annual surplus or deficit (SRA, DFA) curve given in Figure 19, which is also discontinuous. Among the subareas and districts described, the Provo district is unique in that there exists a range of irrigation efficiency in which there is both a zero surplus and deficit.

Demand satisfied by diversions

The percent of demand exerted by potential consumptive use at a given efficiency which is satisfied by present mean diversion, root zone storage, and precipitation may be determined. This quantity is expressed as:

$$PDEM = \frac{DEM - DFA}{DEM} \times 100 \quad . \; . \; . \; . \; . \; . \; . \; . \quad (11)$$

or

$$PDEM = \frac{DEM - SRA}{DEM} \times 100$$

in which PDEM = percent of potential consumptive use satisfied by present mean diversion, root zone storage, and precipitation at a given irrigation efficiency

DEM = mean annual irrigation demand

DFA = annual deficit including root zone storage, diversion, and precipitation

SRA = annual surplus including root zone storage, diversion, and precipitation

For a given irrigation efficiency, the annual surplus (SRA) or deficit (DFA) is determined from Figures 16 to 22 and then demand satisfied (PDEM) is computed. The relation between irrigation efficiency and PDEM is shown in Figures 38 and 39. In general, as the irrigation efficiency increases, the percent of demand satisfied (PDEM) increases. Similarly, a relation between annual surplus or deficit (SRA, DFA) and percent of demand satisfied (PDEM) may be determined. At a given irrigation efficiency, SRA or DFA is obtained from Figures 16 to 22 and PDEM is determined from Figures 38 and 39. The quantities SRA and DFA roughly vary inversely with PDEM as shown in Figures 40 and 41 for the subareas and districts. The irrigation efficiency is not constant along the curve but decreases as the deficit (DFA) increases. All curves cross the abscissa at PDEM equals 100 percent.

CHAPTER 5

WATER MANAGEMENT POTENTIAL

Water management may be defined as the application of technical and organizational skills in order to provide suitable and sufficient water in the desired place and at the desired time for the intended use. The quantitative data presented herein are not combined with specific recommended management decisions. Rather, the data may be used to further certain administrative objectives for either reallocation of water or increasing water supply within the drainage area or conjunction with other adjacent drainage areas. This will involve technical improvements of conveyance and irrigation systems as well as institutional changes such as in law, economics, and organization of distribution companies.

In terms of management decisions, there are several variables which require consideration. These quantities are the surplus or deficit (SRA, DFA), the percent of demand satisfied (PDEM) and the irrigation efficiency (EI). In the Appendix, Figures 16 to 22 show the relation of demand (PDEM) and surplus or deficit (SRA, DFA) at various efficiencies. In addition, Figures 38 to 41 show the relation of percent demand satisfied (PDEM), and mean annual surplus or deficit (SRA, DFA). These curves enable the investigator to determine the value of two variables, given one. The results derived from the curves are summarized in Tables 17 to 23, which follow the example problems.

Example Problems

The use of the tables and graphs can best be explained in terms of specific examples. The Lehi- American Fork area will be considered. A set of small sketches of the three types of curves are shown in Figure 8 in order to illustrate the problems.

Case 1. Given a 35 percent irrigation efficiency, what is the percent of potential consumptive use satisfied under present mean annual diversion and precipitation conditions and what is the additional annual diversion required to completely meet the demand? Refer to Figure 38. At a 35 percent irrigation efficiency, the present crop demand (PDEM) is 81 percent satisfied. The same information is contained in Table 21. Then refer to Figure 18 on the SRA-DFA curve. At a 35 percent irrigation efficiency, the additional annual diversion is 20, 000 acre-feet (AF). The same information is contained in Table 18. This particular case is useful in determining the consequences of estimating efficiency for a given area. A comparison could be made of the net demands of two areas which differed in efficiency.

Case 2. Given an additional divertable quantity of 50, 000 acre-feet (AF) what is the minimum irrigation efficiency necessary

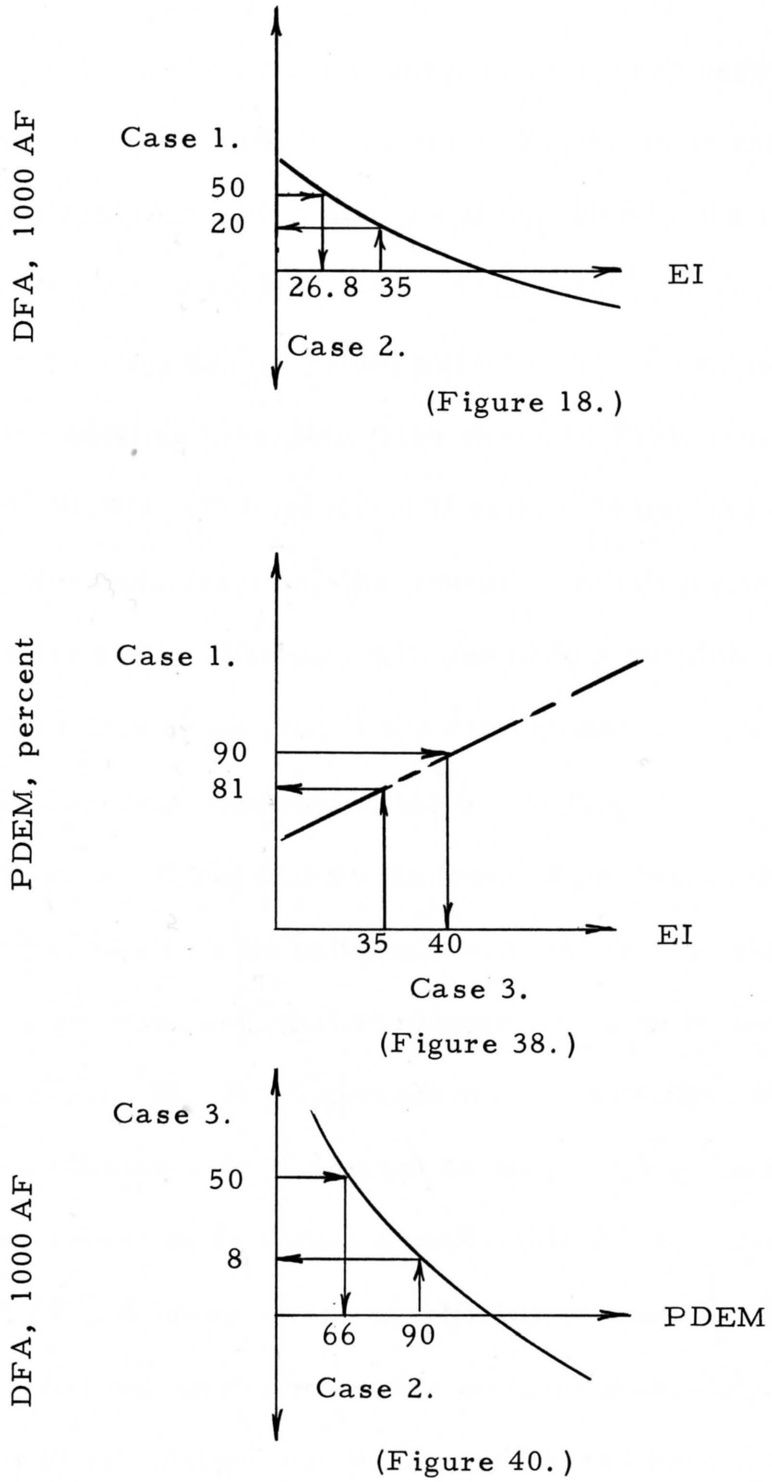

Figure 7. Graphical technique in the solution of text example problems. (Figures are not to scale).

to satisfy crop needs and what percentage of crop needs will this additional diversion satisfy? (Refer to Figure 18 on the SRA-DFA curve and Table 22.) At a demand of 50,000 AF, the required irrigation efficiency is 26.8 percent. Then refer to Figure 40. A 50,000 AF available surplus will be equivalent to 66 percent already satisfied by the existing diversion (also shown in Table 20). Hence, the additional 50,000 AF diversion will satisfy 34 percent of the potential consumptive use, assuming the irrigation efficiency is 25.8 percent. A higher irrigation efficiency will result in a surplus. A solution similar to this may be used in the determination of irrigation efficiency in the event imported water is available.

Case 3. Given that a maximum 90 percent of the potential consumptive use is to be satisfied, what is the minimum irrigation efficiency required and what additional diversion is necessary. Refer to Figure 38. At 90 percent of DEM satisfied, the minimum irrigation efficiency is 40 percent as shown in Figure 38 and Table 23. Then referring to Figure 40 and Table 23, the diversion required is 8,000 AF. A lower irrigation efficiency would result in a lower percentage of demand satisfied and a higher diversion necessary. This type of calculation may be used in cases where total satisfaction of crop needs may not be economically feasible.

Case 4. Given a maximum of 90 percent of the demand to be satisfied and that a maximum of 35 percent irrigation efficiency can be obtained, what is the necessary quantity which requires diverting? Refer to Figure 18 and Table 17 for the quantity DEM. At 35 percent irrigation efficiency DEM equals 105,000 AF; 90 percent of this quantity equals 94,500 AF. Then this requires 10,500 AF to remain as demand. From Case 1 at 35 percent efficiency, the deficit is 20,000 AF. Thus 9,500 (20,000-10, 500) acre-feet requires diverting. This case includes the use of multiple constraints.

The procedure in determining the quantities of the above cases 1 to 3 are summarized in Table 24.

Limitation of Surplus and Deficit Quantities

Caution is necessary in using the surplus and deficit graphs. The mean annual demands, as stated previously, represent the sum of the negative and positive monthly demands. A zero annual deficit is not indicative that monthly deficits are likewise zero. The diversion pattern in practically all areas show high quantities diverted in April and May and low quantities in July and August. Additional information is required in order to determine the quantities of actual seasonal water surplus or shortage. For example, in the Lehi-American Fork subarea at 50 percent irrigation efficiency, there is annual surplus of 6,000 AF. However, the sum of monthly surpluses is 15,000 AF and the sum of monthly deficits is 9,000 AF. Refer to Figure 26 (Appendix) which shows that monthly deficits exist in

Table 17. Diversion demand (DEM) at various irrigation efficiencies (EI).

Subarea or District/EI	DEM, 1000 AF										
	20	25	30	35	40	45	50	55	60	65	70
Heber-Kamas	182	147	121	104	91	80	73	66	60	55	52
Lehi-American Fork	186	150	124	105	93	82	74	67	62	56	53
Provo	234	189	156	134	117	104	94	85	78	72	67
Spanish Fork	654	529	436	370	327	285	261	239	218	200	187
Northern Juab	137	112	91	78	69	61	55	50	46	42	39
Utah Valley	1074	868	716	609	537	471	429	391	358	328	307
Utah Lake drainage	1393	1207	928	791	697	612	557	507	464	425	398

Table 18. Annual surplus or deficit (SRA, DFA) at various irrigation efficiencies (EI).

	SRA (-) or DFA (+), 1000 AF										
Subarea or District/EI	20	25	30	35	40	45	50	55	60	65	70
Heber-Kamas	53	26	8	- 5	-12	-17	-21	-24	-26	-28	-29
Lehi-American Fork	85	58	35	20	8	0	- 6	-11	-15	22	-20
Provo	24	0	7	-29	-45	-58	-69	-78	-85	-92	-99
Spanish Fork	344	245	170	120	81	55	33	17	0	-18	-28
Northern Juab	86	65	49	38	30	25	20	16	12	9	6
Utah Valley	461	303	198	111	47	- 3	-42	-72	-100	-130	-149
Utah Lake drainage	592	394	255	144	62	5	-43	-80	-114	-149	-172
Utah Valley, SRAS or DRAS	450	290	160	80	20	-20	-40	-60	-70	-80	-90
Utah Lake drainage SRAS or DFAS	560	340	190	90	20	-30	-70	-90	-110	-120	-130

Table 19. Annual surplus or deficit (SRA, DFA) at various percent diversion demand satisfied (PDEM).

	SRA (-) or DFA (+), 1000 AF										
Subarea or District/PDEM	50	60	70	80	90	100	110	120	130	140	150
Heber-Kamas	--	--	--	31	15	0	-10	-17	-22	-26	-28
Lehi-American Fork	--	69	40	20	8	0	- 8	-13	-18	-21	--
Provo	--	--	--	--	24	0	-16	-29	-39	-47	--
Spanish Fork	288	170	104	56	25	0	-18	--	--	--	--
Northern Juab	38	24	15	08	--	--	--	--	--	--	--
Utah Valley	--	390	240	130	60	0	-40	-70	-100	-130	--
Utah Lake drainage	--	520	320	170	70	0	-60	-100	-130	-160	--

Table 20. Percent diversion demand satisfied (PDEM) at various annual surplus or deficit (SFA, DFA).

PDEM, percent

Subarea or District / SFA or DFA, 1000 AF	-40	-30	-20	-10	0	10
Heber-Kamas	--	--	125	110	100	93
Lehi-American Fork	--	--	137	115	100	89
Provo	132	121	112	106	100	95
Northern Juab	--	--	--	--	100	76

Subarea or district / SFA or DFA, 1000 AF	-15	-10	-5	0	5	10
Spanish Fork	--	--	--	100	82	71
Utah Valley	--	130	113	100	91	84
Utah Lake drainage	136	121	109	100	92	86

Table 20. (Cont.)

Subarea or district / SFA or DFA, 1000 AF	20	30	40	50	60	70
Heber-Kamas	86	80	75	--	--	--
Lehi-American Fork	81	75	70	66	62	59
Provo	91	--	--	--	--	--
Northern Juab	64	56	--	--	--	--

Subarea or district / SFA or DFA, 1000 AF	15	20	25	30	35	40
Spanish Fork	63	57	53	--	--	--
Utah Valley	78	74	69	66	63	59
Utah Lake drainage	82	78	74	71	68	66

Table 21. Percent diversion demand satisfied (PDEM) at various irrigation efficiencies (EI).

	PDEM, Percent										
Subarea or District / EI	20	25	30	35	40	45	50	55	60	65	70
Heber-Kamas	71	82	93	104	113	121	129	136	143	150	156
Lehi-American Fork	54	61	62	81	90	99	108	116	124	135	141
Provo	90	100	104	121	138	156	163	192	209	228	248
Spanish Fork	48	54	60	68	75	81	88	93	100	109	115
Northern Juab	37	42	46	51	56	59	64	68	74	79	85
Utah Valley	58	65	72	82	91	99	110	119	128	139	148
Utah Lake drainage	58	67	67	82	91	99	108	116	125	135	143

Table 22. Irrigation efficiency (EI) at various annual surplus or deficit (SRA, DFA).

EI, Percent

Subarea or District / SFA or DFA, 1000 AF	-40	-30	-20	-10	0	10
Heber-Kamas	--	--	48.4	38.3	33.0	29.2
Lehi-American Fork	--	--	66.5	53.0	45.0	38.9
Provo	38.5	35.3	32.8	30.5	23.0[b]	21.5
Northern Juab	--	--	--	--	90[a]	64.0

Subarea or District/ SRA or DFA, 1000 AF	-150	-100	-50	0	50	100
Spanish Fork	--	--	--	60.0	46.0	37.5
Utah Valley	70	60.0	51.5	44.5	39.5	35.4
Utah Lake drainage	65.0	57.3	50.4	45.2	40.6	37.3

Table 22. Continued.

SRA or DFA, Subarea or District/ 1000 AF	20	30	40	50	60	70
Heber-Kamas	26.0	23.0	20.5	--	--	--
Lehi-American Fork	34.9	31.8	29.0	26.8	34.8	22.9
Provo	20.3	--	--	--	--	--
Northern Juab	50.0	40.5	34.0	29.9	26.5	23.8

SRA or DFA, Subarea or District/ 1000 AF	150	200	250	300	350	400
Spanish Fork	32.0	27.8	24.5	22.0	--	--
Utah Valley	32.0	39.5	24.2	25.2	23.5	22.0
Utah Lake drainage	34.5	32.0	30.0	28.0	26.5	25.0

[a] Extrapolated value

[b] 23.0 to 28.5

Table 23. Irrigation efficiency (EI) at various percent diversion demand satisfied (PDEM).

	EI, Percent										
Subarea or District / PDEM	50	60	70	80	90	100	110	120	130	140	150
Heber-Kamas	--	--	--	23.5	27.5	33.0	38.5	44.5	50.5	57.5	65.0
Lehi-American Fork	--	23.0	28.7	34.3	40.0	45.8	51.5	57.0	62.9	68.3	--
Provo	--	--	--	--	20.0	23.0[a]	32.0	35.0	38.3	41.0	43.8
Spanish Fork	22.5	30.0	37.0	44.5	51.8	59.0	66.3	--	--	--	--
Northern Juab	34.5	45.3	56.0	67.0	--	--	--	--	--	--	--
Utah Valley	--	22.3	27.7	33.0	38.5	44.0	49.5	55.0	60.5	66.0	--
Utah Lake drainage	--	21.5	27.5	33.4	39.3	45.2	51.0	57.0	63.0	69.0	--

[a] 23.0 to 28.5

Table 24. Summary of calculation process to determine irrigation efficiency (EI), annual surplus or deficit (SRA, DFA), and percent demand satisfied (PDEM).

Case	Given quantity	To determine	See Tables and Figures of specified area	Process
1	EI	PDEM	Table 21 Figures 38, 39	Read direct. Read ordinate value.
		SRA or DFA	Table 18 Figures 16 to 22	Read direct. Read from SRA-DFA curve ordinate value.
2	SRA or DFA	EI	Table 22 Figures 16 to 22	Read direct. Read from SRA-DFA curve absicissa value.
		PDEM satisfied by SRA.	Table 20	Read PDEM direct then PDEM satisfied by DFA = (100 PDEM).
			Figures 40, 41	Read abscissa value and follow as above
3	PDEM	EI	Table 23 Figures 38, 39	Read direct. Read abscissa value.
		SRA or DFA	Table 19 Figures 40, 41	Read direct. Read ordinate value.

August and September while surpluses exist in April, May, and June. This seasonal maldistribution may be solved by the use of more imported water combined by the construction of greater surface storage facilities. If imported water was not available, the conclusion would be that a 9000 AF reservoir is a minimal requirement in order to potentially satisfy all crop needs. The assumption here is that whatever water is diverted for the Lehi-American Fork subarea, that all water will be uniformly distributed according to crop needs within this area. A large reservoir may solve only a few shortage problems if certain users divert more than what is actually needed. Also, this assumes that whatever extra diversion takes place in the early months can be curtailed and can be stored for use in later months.

The figures in Table 25 show the sum of monthly surpluses and deficits for the area at various percent irrigation efficiencies. For example, in the Utah Lake drainage area at 20 percent the sum of monthly deficits (ΣDF) is 594,000 AF while at 50 percent it is 67,000 AF and the sum of monthly surpluses (ΣSR) is 117,000 AF. The range of irrigation efficiency in which both surpluses and deficits exist is shown in Table 26. Above the lower limit efficiency there is a surplus in certain months. Below the upper limit efficiency there is a deficit in certain months. For five areas, including the Utah Lake drainage area, there is a deficit

Table 25. Sum of monthly surpluses (ΣSR) and deficits (ΣDF) at various irrigation efficiencies (EI).

		ΣSR or ΣDF, 1000 AF										
Subarea or District	/EI	20	25	30	35	40	45	50	55	60	65	70
Heber-Kamas	Σ(DF)	55	32	17	8	2	--	--	--	--	--	--
	Σ(SR)	- 2	- 5	- 9	-12	-16	-17	-21	-24	-26	-28	-29
Utah Valley	Σ(DF)	453	303	206	140	95	76	44	30	20	11	5
	Σ(SR)	--	--	- 6	-35	-57	-77	-94	-110	-124	-136	-145
Lehi-American Frk.	Σ(DF)	85	58	36	25	18	12	9	6	4	3	2
	Σ(SR)	--	--	- 2	- 5	- 9	-12	-15	-18	-20	-22	-23
Provo	Σ(DF)	24	0	--	--	--	--	--	--	--	--	--
	Σ(SR)	--	0	- 7	-29	-45	-58	-69	-78	-85	-92	-99
Spanish Fork	Σ(DF)	344	245	170	120	81	57	38	25	15	9	4
	Σ(SR)	--	--	--	--	--	- 5	-11	-18	-21	-25	-26
Northern Juab	Σ(DF)	86	65	49	38	30	25	20	17	15	13	11
	Σ(SR)	--	--	--	--	--	--	- 1	- 2	- 3	- 4	- 4
Utah Lake drainage	Σ(DF)	594	400	272	191	131	94	67	48	34	25	17
	Σ(SR)	--	--	-18	-46	-70	-92	-117	-140	-155	-171	-181

Table 26. Range or irrigation efficiency (20% < EI < 70%) in which annual surpluses and deficits both exist.

Subarea or District	Range of Irrigation Efficiency	
	Lower limit of sum of monthly surpluses	Upper limit of sum of monthly deficits
Heber-Kamas	< 20	42.5
Utah Valley	29	> 70
Lehi-American Fork	29	> 70
Provo	28.5	23
Spanish Fork	42	> 70
Northern Juab	47.5	> 70
Utah Lake drainage	28	> 70

even at 70 percent irrigation efficiency. This is, of course, a mean variation and in years of greater or less water there will be expected greater or less net demand. The implication is that high efficiency alone will not solve the water shortage problem. The early diverted water must be stored to relieve shortage in growing months. In addition, possible carry-over storage from the previous season may relieve shortages. When there is a net annual deficity, the reservoir storage will generally equal the diversion required, provided the necessary additional diversion is met by imported water (assumed not to coincide exactly with crop requirements). When there is a net annual surplus, the reservoir storage will generally equal the total seasonal deficit. Since practically all the excess occurs in the early crop months, conserving part of this supply will enable water use in later crop months when water is in short supply.

Possible Future Irrigation Efficiencies

In Chapter 3, the present irrigation efficiencies for the Utah Lake drainage subareas were estimated and presented in Table 14. In this discussion the future efficiencies will be presented.

There are several technical actions which may increase conveyance efficiency. Three possible improvements are: linings on main canals, gated pieps and linings on laterals and ditches, and decreased operational waste. In addition, the three improvements may be combined resulting in yet higher efficiencies. The three types of improvements and the combinations are arbitrarily assigned values based upon the previous information given in Chapter 3. The three types and their combinations result in six possible improvements. Identical figures are assigned for all areas because further refinement of estimates are unwarranted.

The assigned values range from 82 percent for decreased operational waste to 95 percent for the combination of linings on main canals, gate pipes and linings on laterals and ditches, and decreased operational waste (see Table 27).

There are three factors which affect application efficiency for which values are assigned: better farm irrigation management, call water distribution system, and sprinkler irrigation. The factor of farm irrigation management involves the determination of water needs, control of water quantity, uniformity of application, and personal attention to irrigation. These were briefly discussed in Chapter 3. The delivery system and irrigation method are related. If surface irrigation methods are used, the most efficient distribution system is the call system, whereby the individual irrigator may specify the quantity of water to be delivered. If sprinkler irrigation is used, the most compatible distribution system is continuous flow. Thus, the call distribution system and the sprinkler irrigation method are not combined. Also, since farm irrigation management is

Table 27. Possible increases in conveyance efficiency.

Column	Improvements						
		1	2	3	4	5	6
Subarea or District	[a] E_C	Linings on main canals	Gated pipes & linings on laterals & ditches	Decreased operational waste	Combination 1 & 2	Combination 1 & 3	Combination 1, 2, & 3
Heber-Kamas	69	86	88	82	93	89	95
Utah Valley	80	86	88	82	93	89	95
Lehi-Am. Frk	80	86	88	82	93	89	95
Provo	78	86	88	82	93	89	95
Spanish Fork	82	86	88	82	93	89	95
Northern Juab Valley	70	86	88	82	93	89	95
Utah Lake drainage	78	86	88	82	93	89	95

[a] Present estimated conveyance efficiency.

associated largely with surface irrigation methods, it is combined with the call distribution system as an improvement. This results in four possible combinations of improvements which are shown in Table 28. The assigned values for the areas are identical and range from 60 percent for better farm irrigation management to 72 percent for the combination of better farm irrigation management and sprinkler irrigation.

The products of the combinations of conveyance and application efficiencies yield values of potential irrigation efficiencies. Since there are six conveyance improvements and four application improvements, there are 24 different irrigation efficiency combinations (EI). The values of EI vary from 49 percent to 68 percent. The irrigation efficiency of 68 percent includes linings on main canals, gated pipes and linings on laterals and ditches, decreased operational waste, better farm irrigation management, and sprinkler irrigation. This value appears to be the practical upper limit in irrigation efficiency over a large area.

Surpluses and Excesses for Present and Future Efficiencies

The surplus or excess considering root zone capacity may be determined for both present and future irrigation efficiencies. For the purposes of this discussion, several quantities will be determined for the Utah Lake drainage subareas:

Table 28. Possible increases in application efficiency.

Subarea or district	$^{a}E_A$	Improvements 1 Better farm irrigation management	 2 Combination 1 & call distribution system	 3 Sprinkler irrigation	 4 Combination 1 & 3
Heber-Kamas	47	60	63	65	72
Utah Valley	46	70	63	65	72
Lehi-Am. Fork	41	60	63	65	72
Provo	45	60	63	65	72
Spanish Fork	50	63	63	65	72
Northern Juab Valley	50	63	63	65	72
Utah Lake drainage	46	60	63	65	72

[a]Present estimated application efficiency.

(1) Annual diversion presently required (DFA), the percent of potential consumptive use satisfied by the diversion under the given irrigation efficiency (PDEM), and the sum of the monthly deficits (Σ DF).

(2) Annual diversions presently required (DFA) in order to meet arbitrarily specified figures of PDEM as shown in Table 29, column 6. The potential consumptive use for the Spanish Fork district, and Northern Juab Valley subarea will be assumed to be slowly met. For this reason, PDEM is given as 70 percent. Due to the greater supply in Lehi-American Fork and Provo districts, a full 100 percent PDEM is assumed. The 90 percent figure for Heber-Kamas is assumed because of greater potential comsumptive use downstream.

(3) Annual diversion required (DFA) in the future, the percent of potential consumptive use satisfied by the diversion under the given irrigation efficiency (PDEM), and the sum of the monthly deficits. The maximum irrigation efficiency of 68 percent is assumed.

(4) Annual diversion required (DFA) in the future in order to meet arbitrarily specified figures of PDEM as shown

in Table 30, column 6. The figures of PDEM are identical to those assumed for present efficiencies.

All the demand, surplus, and deficit quantities for the above four conditions were determined by the use of the graphs in Figures 16 to 22, 31 to 37, 38, and 39, supplemented by simple arithmetic as indicated on Tables 29 and 30.

The results are shown in Tables 29 and 30 for the present and future estimated irrigation efficiencies, respectively. In Table 29, column 3 the annual surpluses or deficits are shown. In Utah Valley, the Lehi-American Fork district has a deficit which is just equal to the surplus of the Provo district, which has a magnitude of 29,000 acre-feet.
The other three areas of Heber-Kamas (4000 AF),

Table 29. Tabular calculations for Utah Lake drainage area sample problem--present irrigation efficiency (EI).

(1) Subarea or district	(2) Present EI, percent	(3) SRA or DFA, 1000 AF	(4) PDEM, percent	(5) DEM, 1000 AF	(6) Req'd PDEM, percent	(7) SRA or DFA remaining, 1000 AF	(8) SRA or DFA net (3)-(7) 1000 AF	(9) Σ DF, 1000 AF
Heber-Kamas	32	4	98	114	90	11	-7	14
Lehi-Am. Fork	32	29	76	116	100	0	29	31
Provo	35	29	120	134	100	0	-29	0
Spanish Fork	42	69	76	310	70	93	-24	69
No. Juab	35	38	51	78	70	23	15	38
Totals								
Utah Valley	37	69	87	--	--	--	- 24	10
Utah Lake drainage	36	111	86	--	--	--	- 16	152

Col. (2), (6) given
col. (3), (4), (5) from Figures 27-33; 51, 52
col. (7) = col. (5) x [1-col. (6)]
col. (8) = col. (3) - col. (7)
col. (9) = from Figures 55-61
SRA = annual surplus
DFA = annual deficit
PDEM = percent demand satisfied
DEM = annual demand
Σ DF = sum of monthly deficits

Table 30. Tabular circulation for Utah Lake drainage area sample problem-future irrigation efficiency (EI).

(1) Subarea or district	(2) Future EI, percent	(3) SRA or DFA 1000 AF	(4) PDEM, percent	(5) DEM, 1000AF	(6) Req'd PDEM, percent	(7) SRA or DFA remaining 1000 AF	(8) SRA net 1000 AF	(9) Σ DF, 1000 AF
Heber-Kamas	68	-28	153	55	90	6	-34	0
Lehi-Am. Fork	68	-21	139	59	100	0	-21	2
Provo	68	-96	>200	69	100	0	-96	0
Spanish Fork	68	-21	112	19	70	57	-78	5
Northern Juab	68	7	81	40	70	12	-5	12
Totals								
Utah Valley	68	-138	144	--	--		-195	7
Utah Lake drainage	68	-159	139	--	--		-234	19

col. (2), (6); given
col. (3), (4), (5) from Figures 27-33; 51, 52
col. (7) = col. (5) [1-col. (6)]
col. (8) = col. (3) - col. (7)
col. (9) from Figures 55 to 61

SRA = annual surplus
DFA = annual deficit
PDEM = percent demand satisfied
DEM = annual demand
Σ DF = sum of monthly deficits

Spanish Fork (69,000 AF), and Northern Juab Valley (38,000 AF), and Northern Juab Valley (38,000 AF), are all water short. The sum for Utah Valley is a net deficit of 69,000 AF and for the Utah Lake drainage area of 111,000 AF. These figures neglect the contribution of pumped and flowing groundwater which amount to 65,000 AF in Utah Valley and 10,000 to 17,000 AF in Northern Juab Valley. The subarea which relatively is most water deficient is the Northern Juab Valley, with only 51 percent of its crop potential consumptive use being satisfied at the given irrigation efficiency (PDEM as shown in column 4). The Utah Lake drainage area as a whole has 86 percent of crop demand satisfied. If the satisfaction of all potential consumptive use were limited in certain areas, surpluses would be possible. For complete satisfaction of crop demand the limits of PDEM would be as shown in column 4. If arbitrary values of PDEM were selected as shown in column 6, the resulting demands are those shown in column 8. The last column (9) shows the sum of the monthly deficits (ΣDF). The Provo area has no month in which deficits exist at the given efficiency. This would indicate that the months in which surpluses exist could possibly be reallocated to other areas. Both the Spanish Fork and Northern Juab Valley areas are similar in that in no month are negative demands (surpluses) present. This shows that greater water quantities must be supplied at the required time, or if water is only deliverable at other times, storage facilities should be provided. In the Lehi-American Fork district, the sum of monthly deficits exceeds the annual deficit. This means that at some month, a surplus exists. If the surplus quantity is significant, storage facilities may be utilized in order to conserve it for use in months of water shortage. In this area also, greater water supplies are required annually.

The surpluses or deficits for the ultimate future irrigation efficiency of 68 percent are shown in Table 30. In all subareas, except for Northern Juab Valley, there are annual surpluses (column 3). However, in the Lehi-American Fork and Spanish Fork districts, there exists deficits in certain months. These quantities amount to 2000 AF for Lehi-American Fork (21, 000 AF surplus annually) and 5000 AF for Spanish Fork (21, 000 AF surplus annually). With the surpluses, the shortages could easily be met provided some storage facilities are available. For Utah Valley, the surplus is 138, 000 AF and for the Utah Lake drainage area it is 159, 000 AF. When arbitrary PDEM figures are assumed (column 6), there is, of course, more surplus for the Heber-Kamas, Spanish Fork and Northern Juab Valley areas. Due to the existence of shortages in certain months, despite the annual net surplus, it may be necessary to determine which months deficits exist. The monthly deficits (DF) for the various areas were determined from Figures 24 to 30 at the present and maximum future irrigation efficiencies (see Table 31). The deficits exist

Table 31. Monthly surplus or deficit (SR, DF) at present and future irrigation efficiencies (EI).

Subarea or district	EI[a]	SR (-) or DF (+) 1000 AF							
		Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Sum
Heber-Kamas	32	--	-10	0	0	10	4	--	4
	68	--	-16	0	0	0	0	--	-28
Lehi-American Fork	32	0	-3	0	5	17	8	2	29
	68	-3	-12	-7	0	0	1	0	-21
Provo	35	0	-10	-8	0	0	-11	0	-29
	68	-2	-22	-21	-14	-16	-18	-3	-96
Spanish Fork	42	0	-1	0	21	36	11	2	69
	68	-1	-20	0	0	5	0	0	-21
Northern Juab	35	0	0	0	15	14	7	2	38
	68	-1	-3	0	2	6	3	0	7
Utah Valley[b]	37	0	-14	-8	26	53	8	4	69
	68	-11	-54	-28	-14	-11	-17	-3	-138
Utah Lake drainage[b]	36	0	-24	-8	41	76	19	6	111
	68	-12	-73	-40	-12	-5	-14	-3	-159

[a]Present and maximum future irrigation efficiencies.

[b]Sum of respective components area demands.

principally in the months of July through September while surpluses exist in the months of April and May. For example, in Heber-Kamas where the sum of monthly deficits (13, 000 AF) exceed the net annual deficit (4000 AF) at present efficiency, the surplus is only in May (10, 000 AF) while the deficits are in August (10, 000 AF) and September (4, 000 AF).

There are other future possible irrigation efficiencies for which deficits and shortages may be determined. The deficits and shortages for all 24 combinations of conveyance and application efficiencies in all subareas are shown in Table 32. The column numbers refer to the number combination of conveyance and application efficiency improvement as previously cited in Tables 27 and 28. The surpluses in the Utah Lake drainage area vary from 33, 000 AF at the low efficiency of 49 percent to 159, 000 AF at the high efficiency of 68 percent.

The annual and monthly deficits or shortages for the areas and at the present and maximum future irrigation efficiencies are illustrated graphically in Figures 8 to 15. The graphs usually begin in surplus, continue decreasing then reach near zero surplus at June, show deficit in July and August, and finally decrease deficit at October. The exception to this general trend is the Provo subarea, where there is either zero or no deficit.

Table 32. Annual surplus or deficit (SRA, DFA) at various future efficiencies (EI).

	SRA (-) or DFA (+), 1000 AF							
Column of E_C[a]	3	1 ; 3	2 ; 3 ; 5	1	2	1; 4 ; 5	2;6	5
Column of E_A[b]	1	1 ; 2	1 ; 3 ; 1	2	2	3 ; 1 ; 2	3;1	3
Area/Future EI	49	52	53	54	55	56	57	58
Heber-Kamas	-20	-23	-23	-24	-24	-25	-25	-25
Utah Valley	-34	-57	-64	67	-77	-82	-85	-95
Lehi-Am. Fork	-5	9	-10	-10	-12	-12	-13	-15
Provo	-67	-73	-75	-76	-79	-80	-81	-84
Spanish Fork	38	25	21	19	14	10	9	4
Northern Juab	21	18	18	17	16	15	14	16
Utah Lake drainage	-33	-62	-69	-74	-85	-92	-94	-104
Column of E_C[a]	3; 4	4; 6	1; 6	2	5	4	6	
Column of E_A[b]	4; 2	3; 2	4; 3	4	4	4	4	
Area/Future EI	59	60	62	63	64	67	68	
Heber-Kamas	-26	-26	-27	-27	-27	-28	-28	
Utah Valley	-98	-104	-113	-119	-124	-134	-138	
Lehi-Am. Fork	-15	-16	-17	-18	-19	-20	-21	
Provo	-94	-87	-88	-91	-91	-95	-96	
Spanish Fork	1	-1	-8	-10	-14	-19	-21	
Northern Juab	13	12	11	10	10	8	7	
Utah Lake drainage	-113	-118	-129	-136	-161	-154	-159	

[a] Column numbers of Table 27.
[b] Column numbers of Table 28.

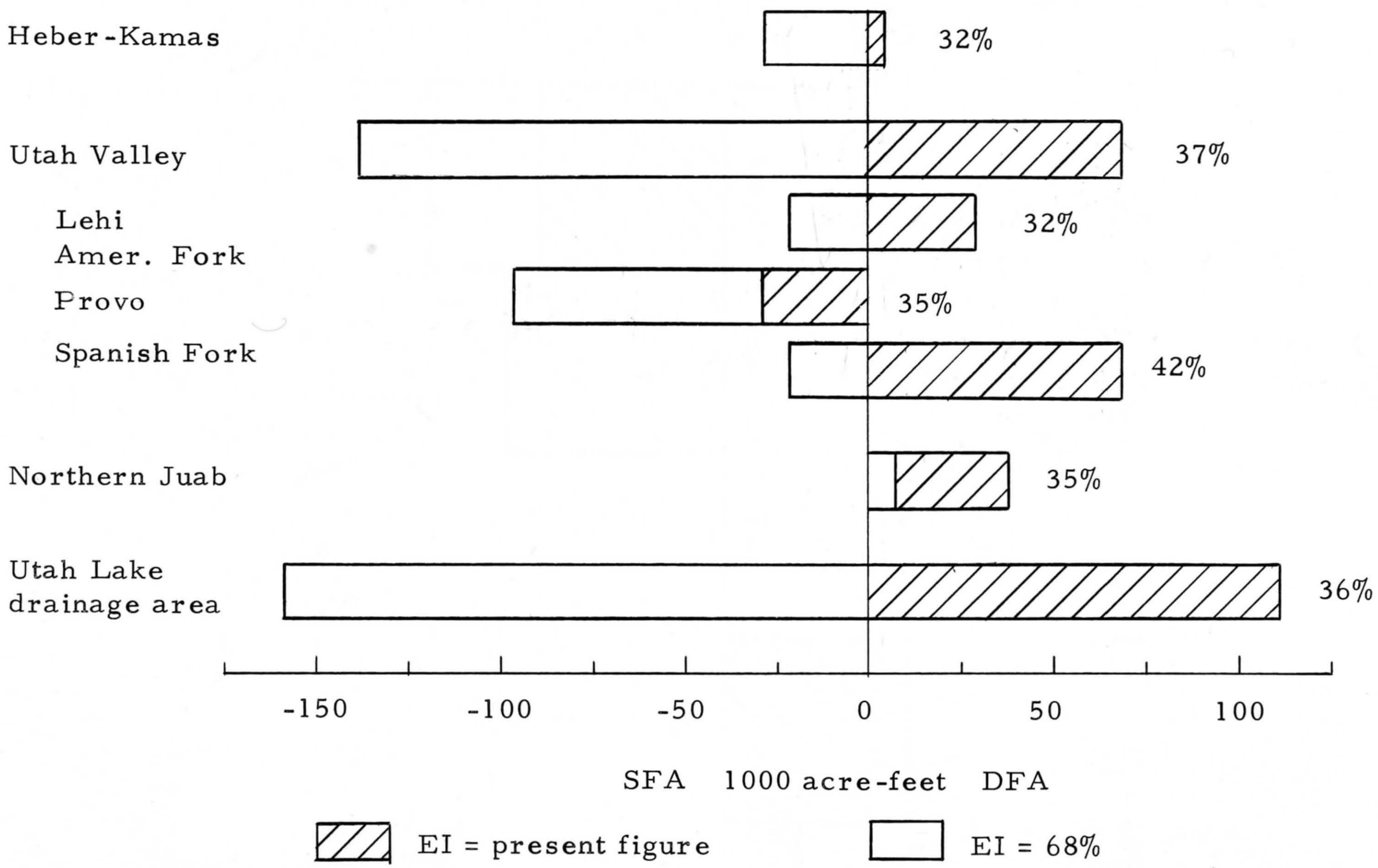

Figure 8. Annual surplus (SFA) and deficit (DFA) at present and future irrigation efficiencies (EI).

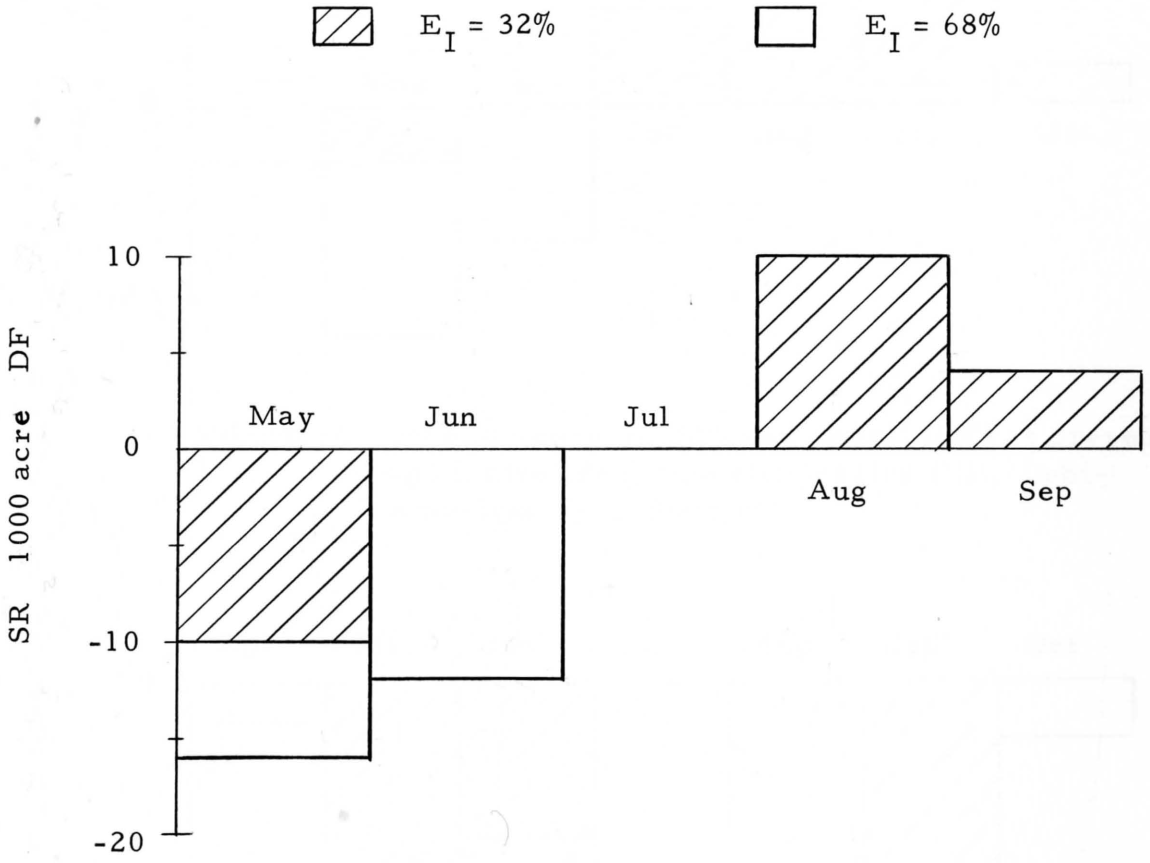

Figure 9. Monthly surplus (SR) and deficit (DF) at present and future irrigation efficiencies (EI), Heber-Kamas subareas.

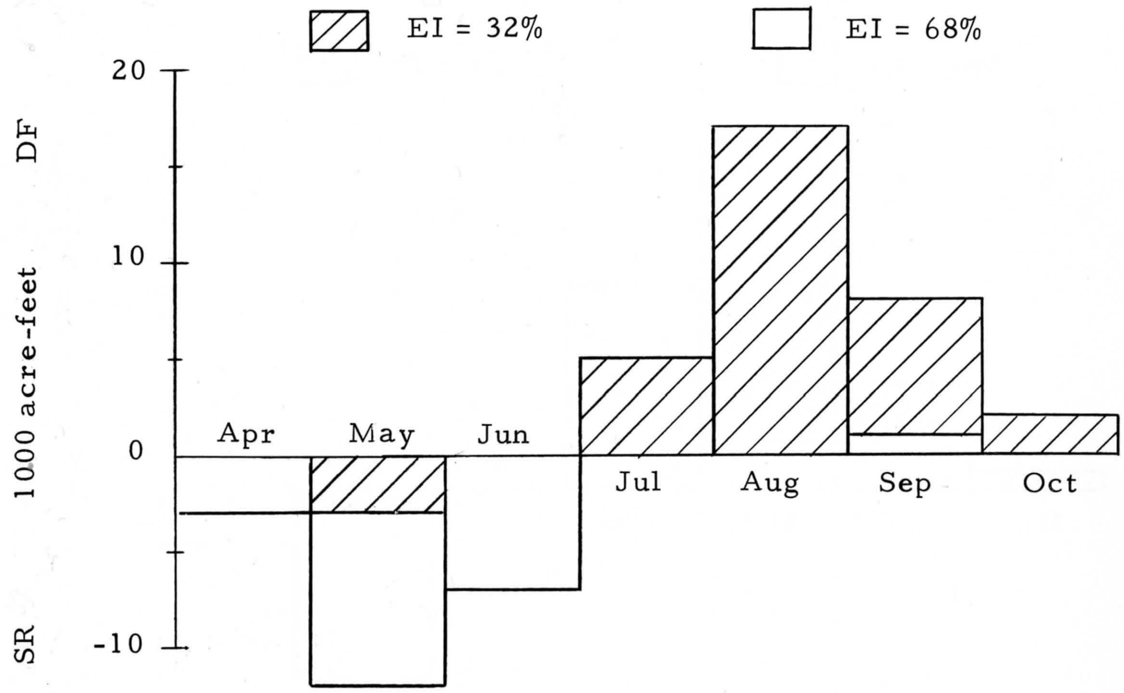

Figure 10. Monthly surplus (SR) and deficit (DF) at present and future irrigation efficiencies (EI), Lehi-American Fork district.

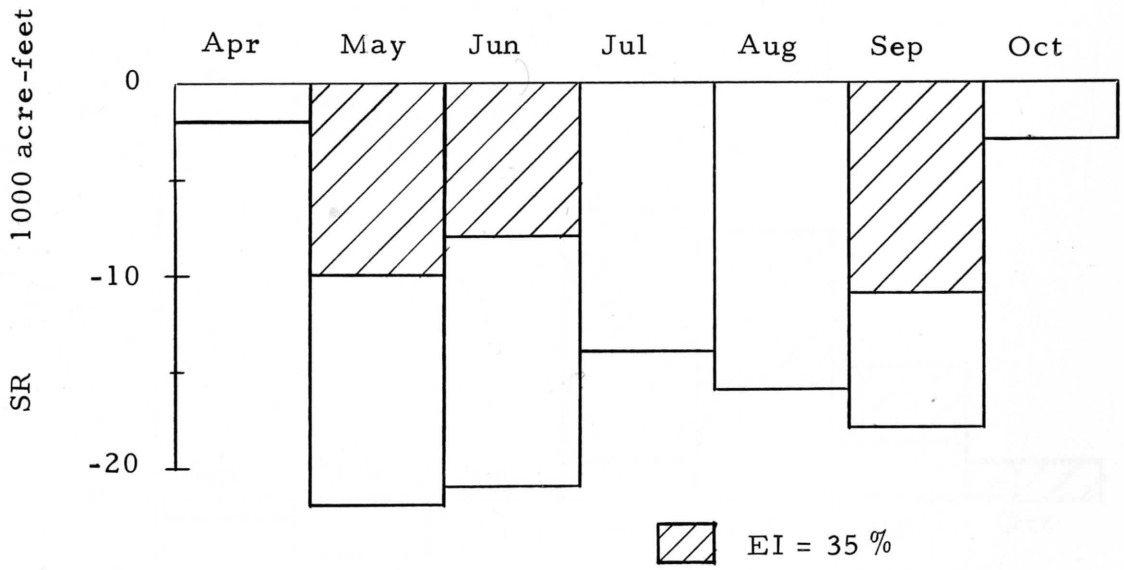

Figure 11. Monthly surplus (SR) and deficit (DF) at present and future irrigation efficiencies (EI), Provo district.

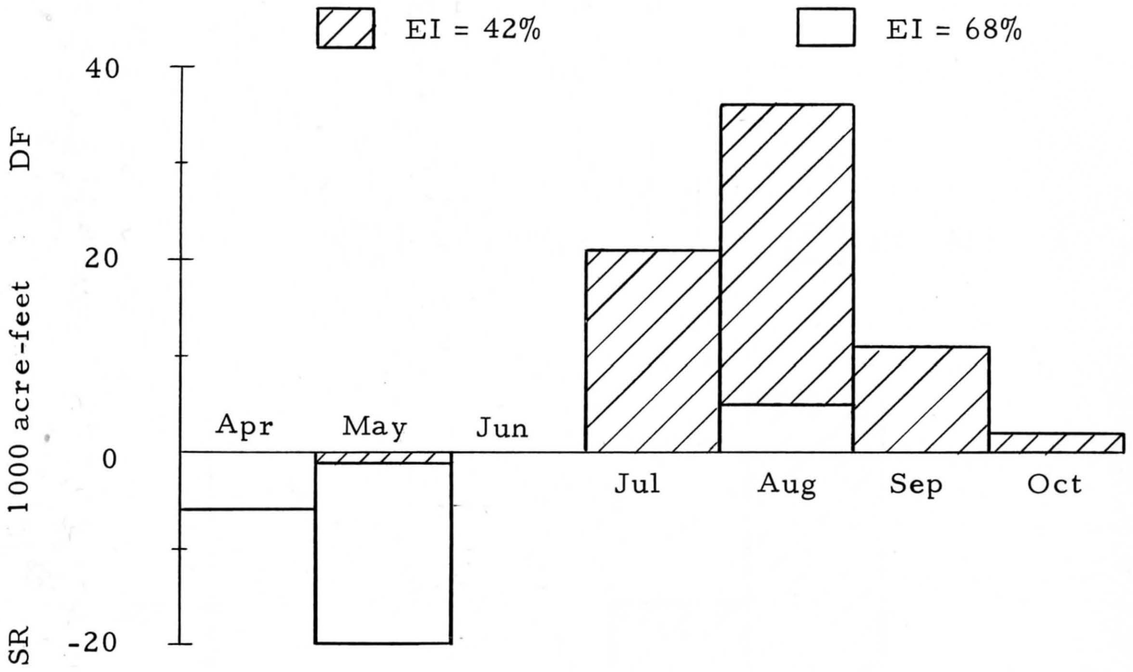

Figure 12. Monthly surplus (SR) and deficit (DF) at present and future irrigation efficiencies (EI), Spanish Fork district.

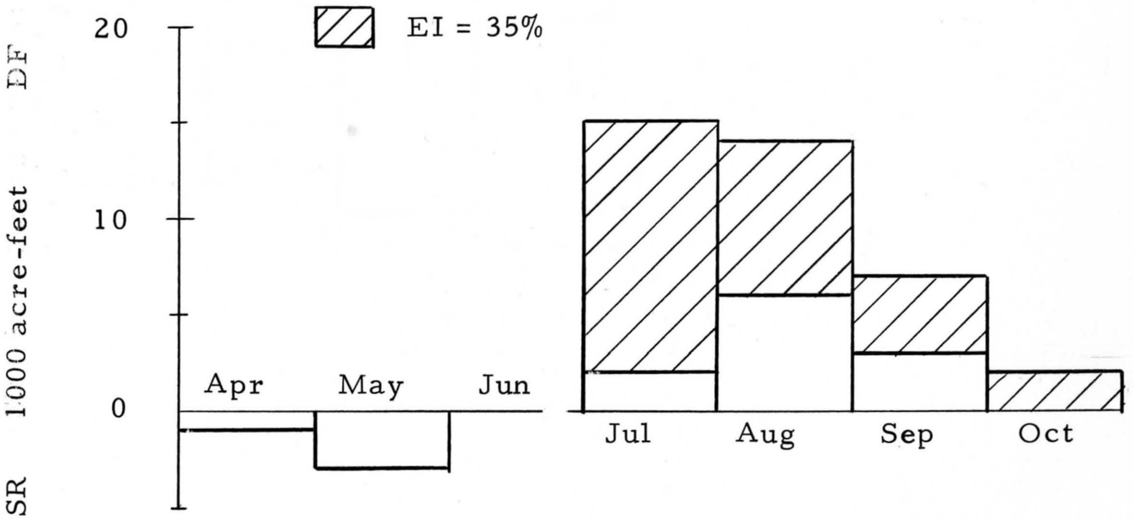

Figure 13. Monthly surplus (SR) and deficit (DF) at present and future irrigation efficiencies (EI), Northern Juab subarea.

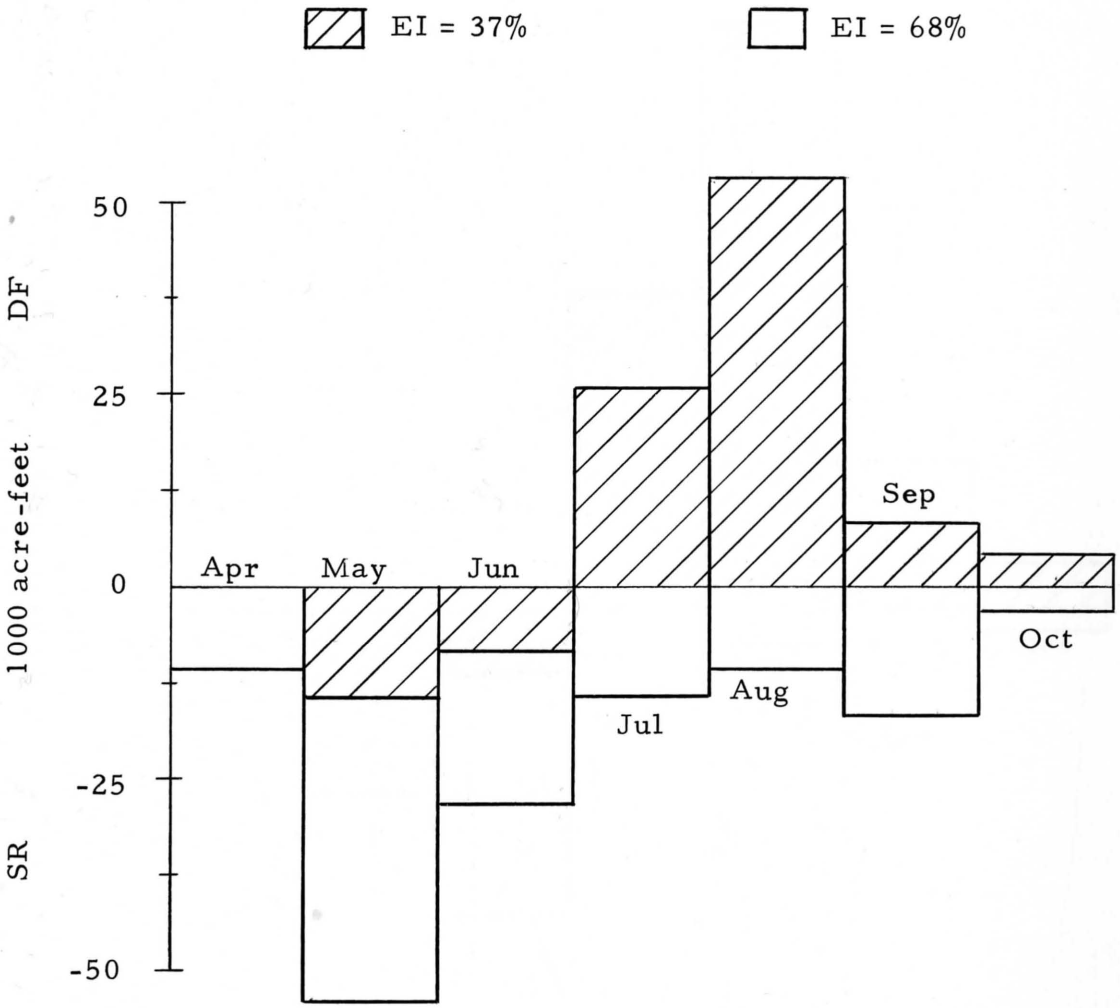

Figure 14. Monthly surplus (SR) and deficit (DF) at present and future irrigation efficiencies (EI), Utah Valley subarea.

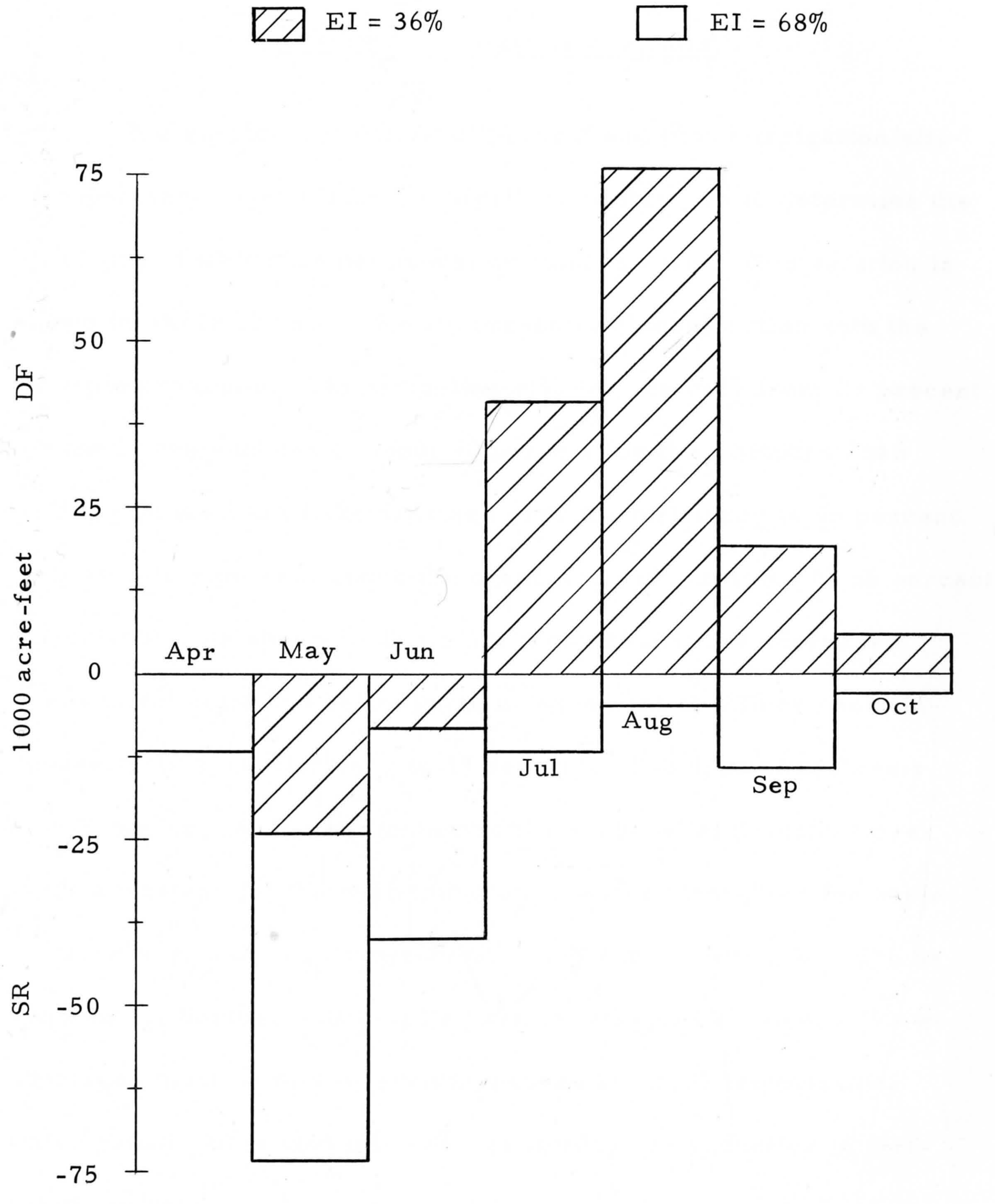

Figure 15. Monthly surplus (SR) and deficit (DF) at present and future irrigation efficiencies (EI), Utah Lake drainage area.

Efficiency at Zero Net Demand

The surplus and deficit at present and future irrigation efficiencies were determined. A corollary problem is to determine the efficiency at which the net annual demand is zero. This solution is shown in Table 22 as previously presented in conjunction with the example problems. The irrigation efficiencies vary from 23 percent for the Provo subarea to about 90 percent for the Northern Juab Valley. In the Utah Lake drainage area the efficiency is 45 percent. This is only 9 percent above the present estimated value of 36 percent. Conceivably, as shown in Table 32, a combination of decreased operational waste and better farm management practices could increase irrigation efficiency to 49 percent. The crucial problems are, however, (a) the attainment of these remedial practices over large areas and (b) the redistribution of water throughout the basin in order to satisfy local shortages. Very high efficiencies such as required in Northern Juab Valley are not attainable. Hence, water shortages must be met by such measures as water importation, water reuse, increased groundwater mining, or reduction in irrigated cropland.

CHAPTER 6

CONCLUSION

The crop needs are not adequately being satisfied in the Utah Lake drainage area. The problem is twofold. First, under present assumed irrigation efficiencies, there is a excess of diversion in the Provo district beyond calculated crop requirements. This requires measures for reallocation of water to other water deficient areas, particularly the Spanish Fork district and Northern Juab Valley subarea. Second, there is a greater need for control of available quantities in order to make diversion coincide more closely in time with the crop potential consumptive use. The common pattern is excessive diversions in May and insufficient diversions in July through September. This will require modifications in the form of more storage facilities to make available water in later crop months.

In the Heber-Kamas subarea, under present efficiencies, a deficiency exists in the months of August and September. Since this area is upstream from the Wasatch Front areas a redistribution of excess water from lower elevation areas is not possible. All water requirements must be met within the area or imported from other basins. The excess quantity in May is not truly meaningful when included in the Utah Lake drainage area calculations because any inefficiency from upstream areas results in high percentage of surface return flow to the Wasatch Front areas. An increase in efficiency to the ultimate of 68 percent would cancel out all deficits, but increase surplus quantities in May and June to 28,000 acre-feet (AF).

In the Lehi-American Fork district, under present efficiencies, deficits exist in all months including and following July and is highest in July at 17,000 AF. Much of the deficit could be canceled if the surpluses in the nearby Provo district (which amount to 18,000 AF in the months of May and June) were diverted for the months of July and August (22,000 AF). An increase of irrigation efficiency to 68 percent would cancel nearly all deficits in later crop months (only 1000 AF in September remaining) and would greatly increase surpluses in May to 12,000 AF.

The Provo district is, by far, the most water plentiful area within the Utah Lake drainage area. At no time, under present efficiencies, do deficits exist, while surpluses totaling 29,000 AF exist in May, June and September. If the irrigation efficiency increased to 68 percent, surpluses would be present in every month.

The Spanish Fork district is, in absolute quantities, the most water deficient area. Deficits are present from July onwards, with a maximum of 36,000 AF in August. The future deliveries under the Central Utah Project to be constructed by the U. S. Bureau of Reclamation, should help offset the shortages. Although not quantitatively and separately determined, much of this deficit is in the southern part of this district. Of the mean annual potential consumptive use of 131,000 AF, about 64,000 AF is from the Strawberry Highline, Santaquin and Goshen areas (see Appendix). A rise in irrigation efficiency (to 68%) would nearly eliminate deficits in the later months and result in a net surplus of 21,000 AF.

The Northern Juab Valley is the only subarea in which, under present irrigation efficiencies, no surpluses exist. Crop needs are satisfied in April through June but from July onwards shortages exist which total 38,000 AF. Relatively, this area is the most water short, only 51 percent of the demand (38,000 AF deficit remaining) being satisfied (PDEM). Even a maximum irrigation efficiency of 68 percent will not remove deficits. The Northern Juab Valley requires imported water.

There is greater potential for comprehensive water management in the Utah Valley because of the closely adjacent croplands and common sources of supply. Under present irrigation efficiencies, even if water were redistributed to areas of greatest demand, substantial deficits would remain. The July and August deficit totals 79,000 AF under present irrigation efficiencies. Increasing the efficiency to 68 percent would eliminate all deficits. Also, under the future ultimate efficiency, there would be surpluses in all crop months due primarily to the contribution of the Provo district surpluses.

This study shows the effect of irrigation efficiency upon demand, surplus, and deficit in the Utah Lake drainage area. The paucity of efficiency figures make some of the results appear fictitious. However, under the present state of knowledge, it is hoped that the results will add useful information. This shows that there is great potential in the water management field for the improvement of administrative and technical actions in irrigation water supply. Improved irrigation conveyance and application facilities combined with equitable water allocation will aid in the economic use of water resources for the benefit of the area's people.

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APPENDICES

Appendix A

Figures 16 to 41

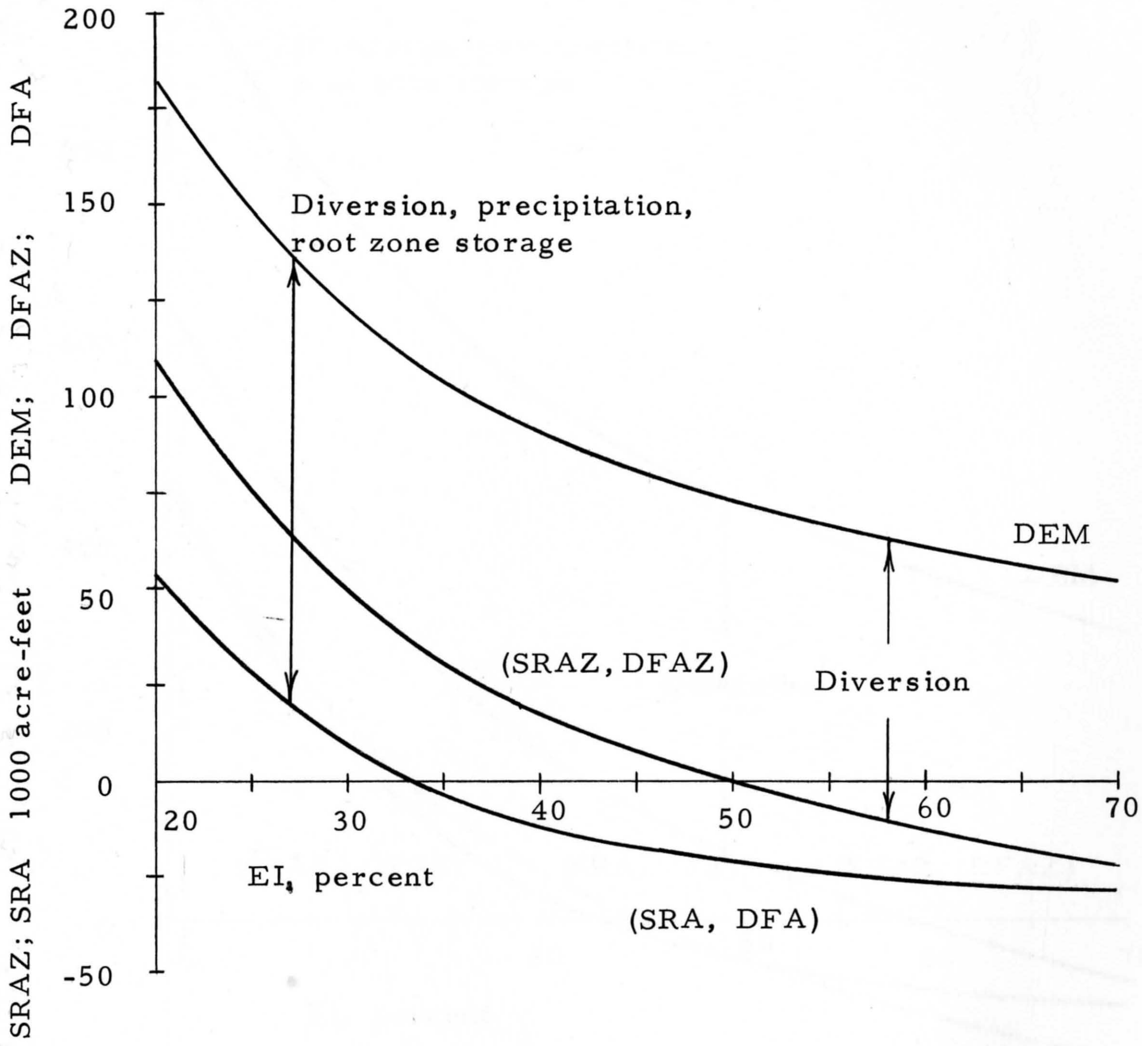

Figure 16. Annual demand (DEM), annual surplus (SRA) or deficit (DFA) excluding root zone storage, and annual surplus (SRAZ) or deficit (DFAZ) including root zone storage vs irrigation efficiency (EI), Heber-Kamas subareas.

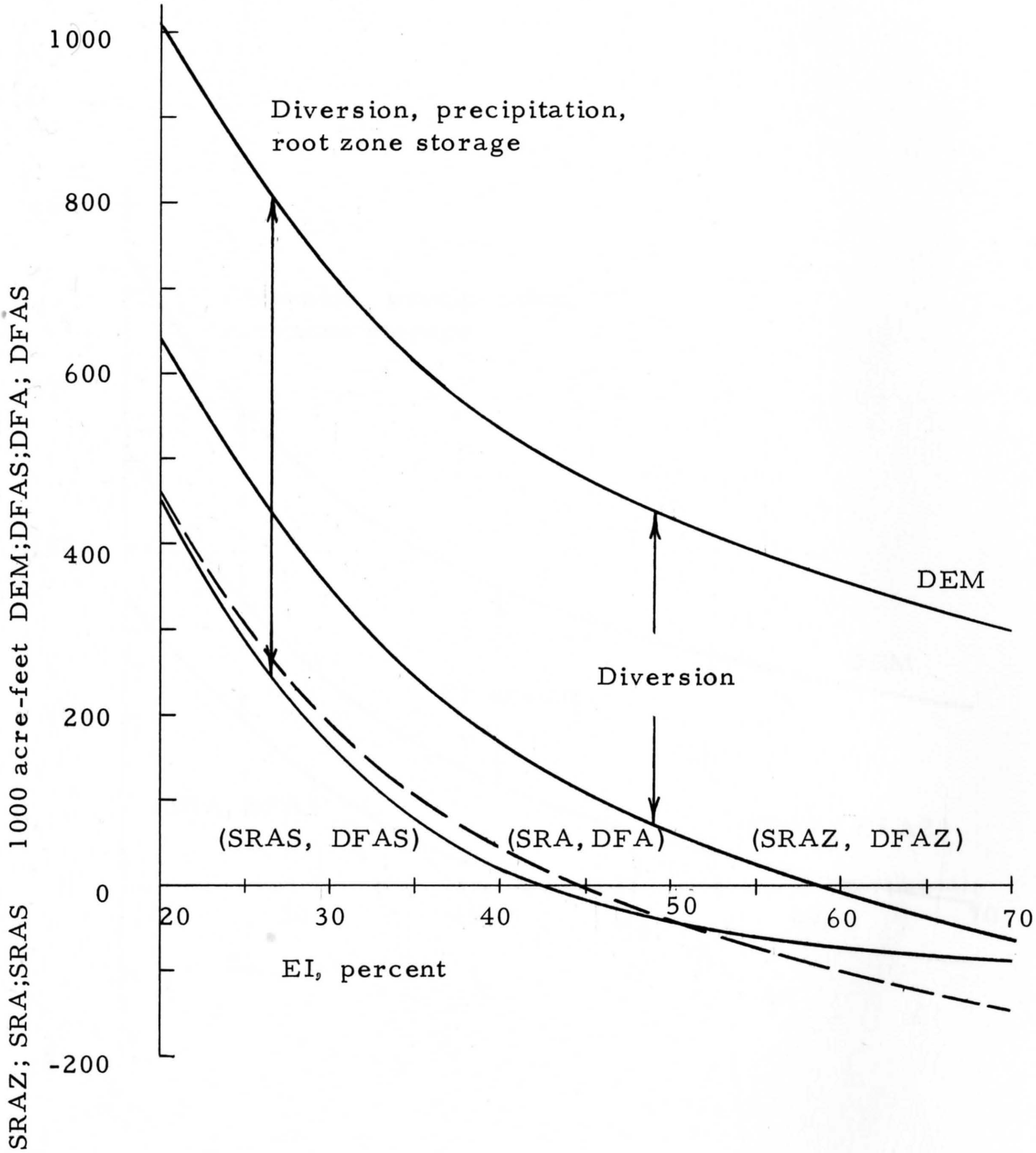

Figure 17. Annual demand (DEM), annual surplus (SRAZ) or deficit (DFAZ) excluding root zone storage, and annual surplus (SRA) or deficit (DFA) including root zone storage vs irrigation efficiency (EI), Utah Valley subarea.

(SRAS, DFAS) curve same as (SRA, DFA) except assumes uniform water application over entire area.

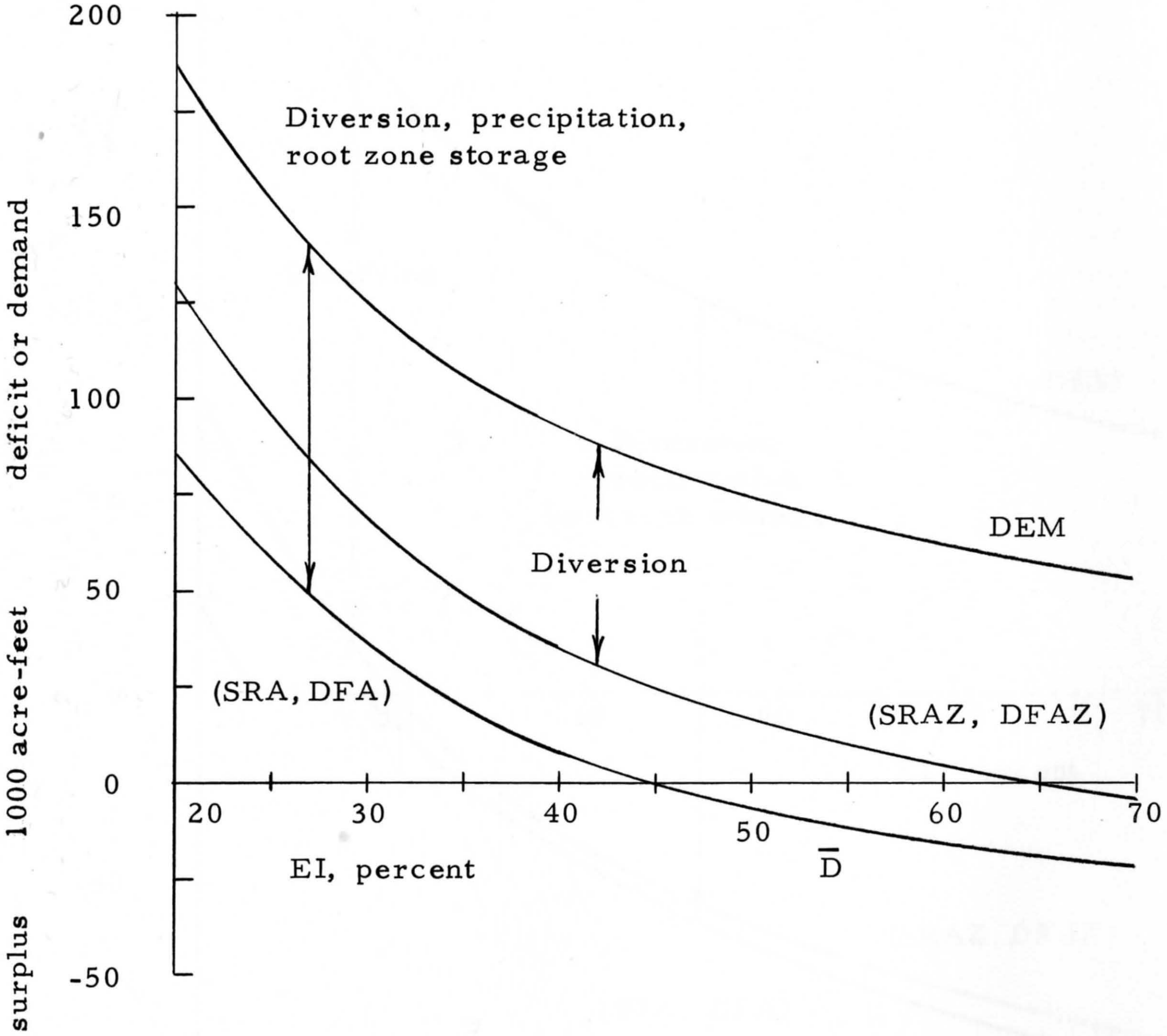

Figure 18. Annual diversion demand (DEM), annual surplus (SRAZ) or deficit (DFAZ) excluding root zone storage, and annual surplus (SRA) or deficit (DFA) including root zone storage vs irrigation efficiency (EI), Lehi-American Fork district.

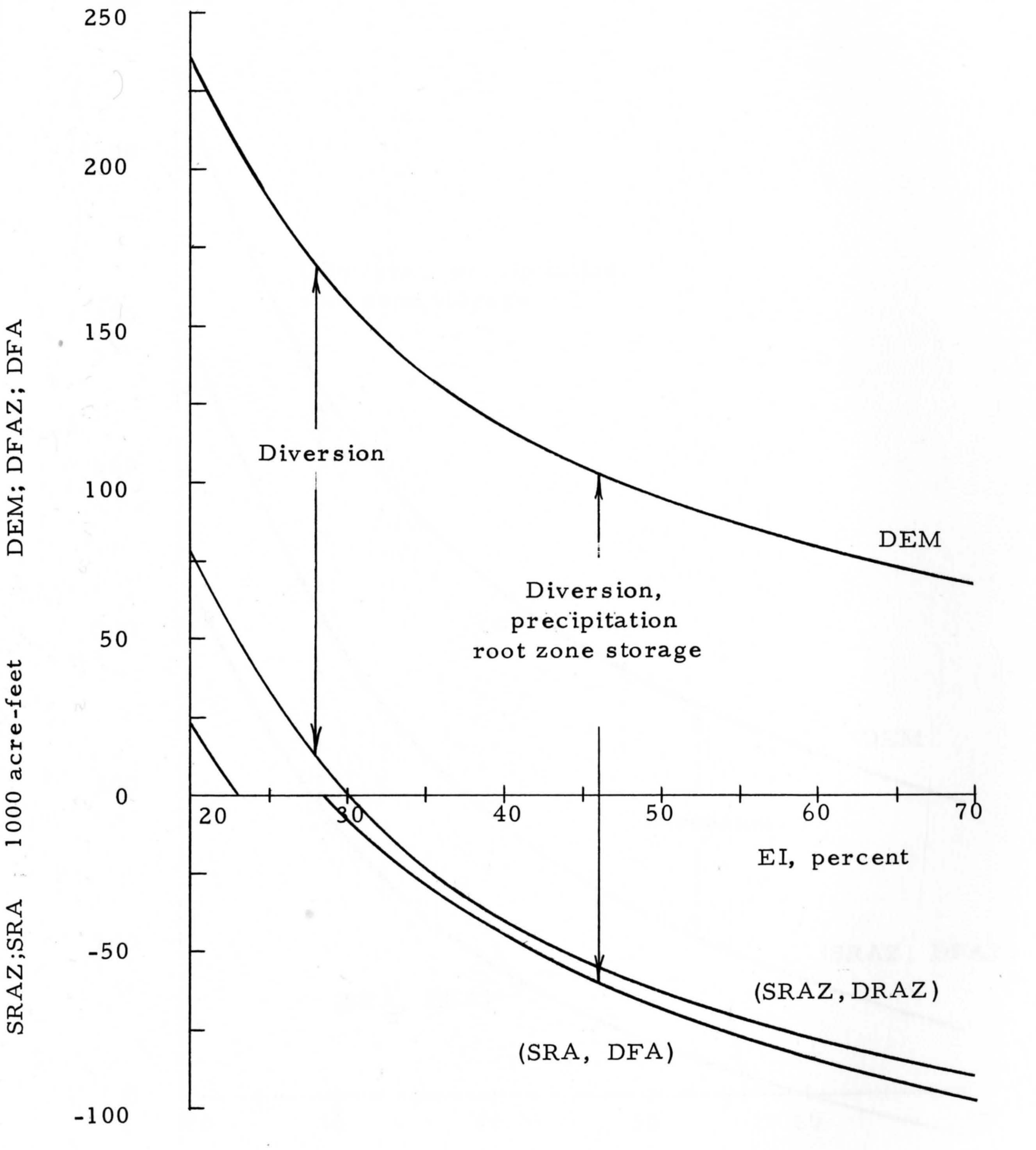

Figure 19. Annual diversion demand (DEM), annual surplus (SRAZ) or deficit (DFAZ) excluding root zone storage, and annual surplus (SRA) or deficit (DFA) including root zone storage vs irrigation efficiency (EI), Provo district.

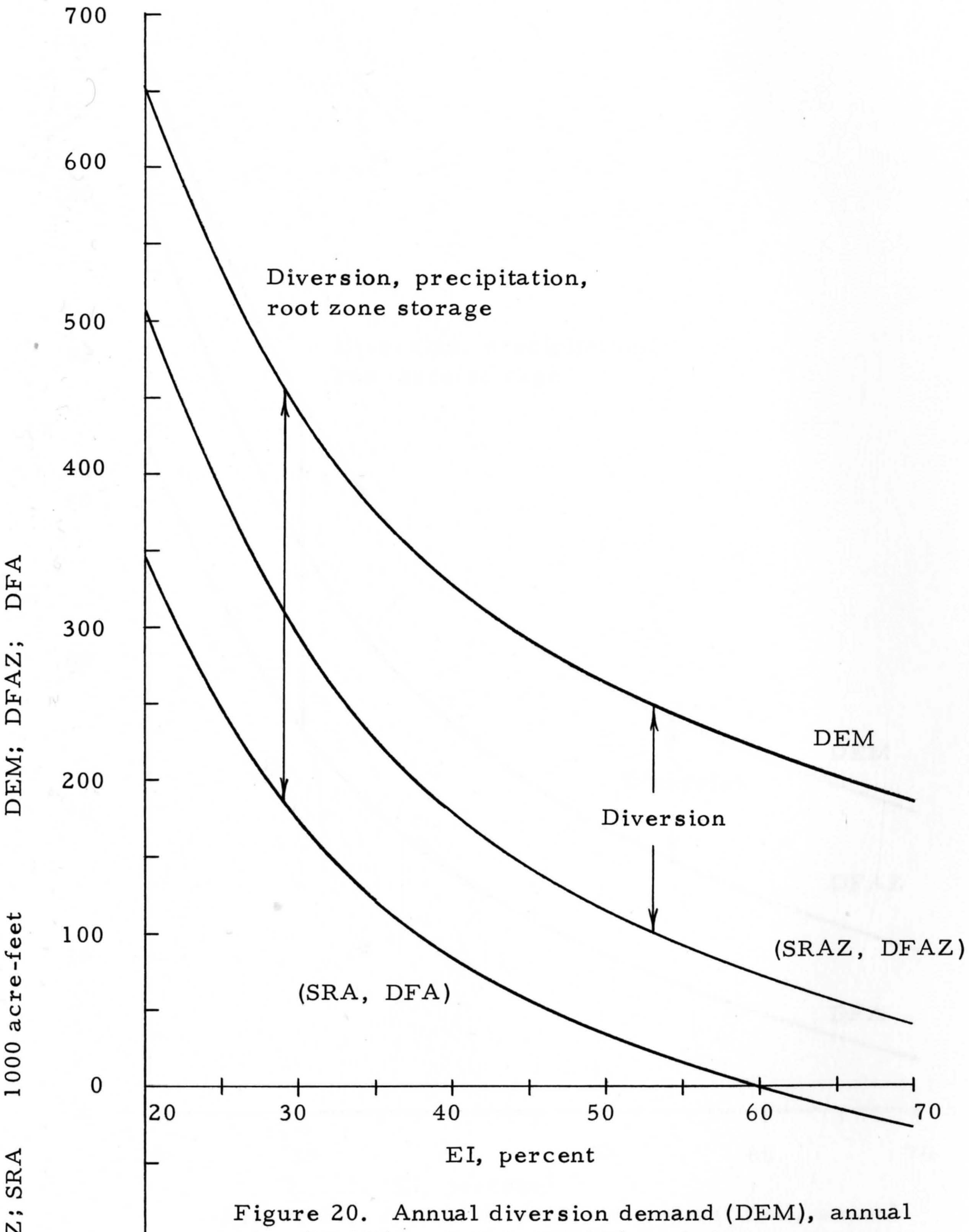

Figure 20. Annual diversion demand (DEM), annual surplus (SRAZ) or deficit (DFAZ) excluding root zone storage, and annual surplus (SRA) or deficit (DFA) including root zone storage vs irrigation efficiency (EI), Spanish Fork district.

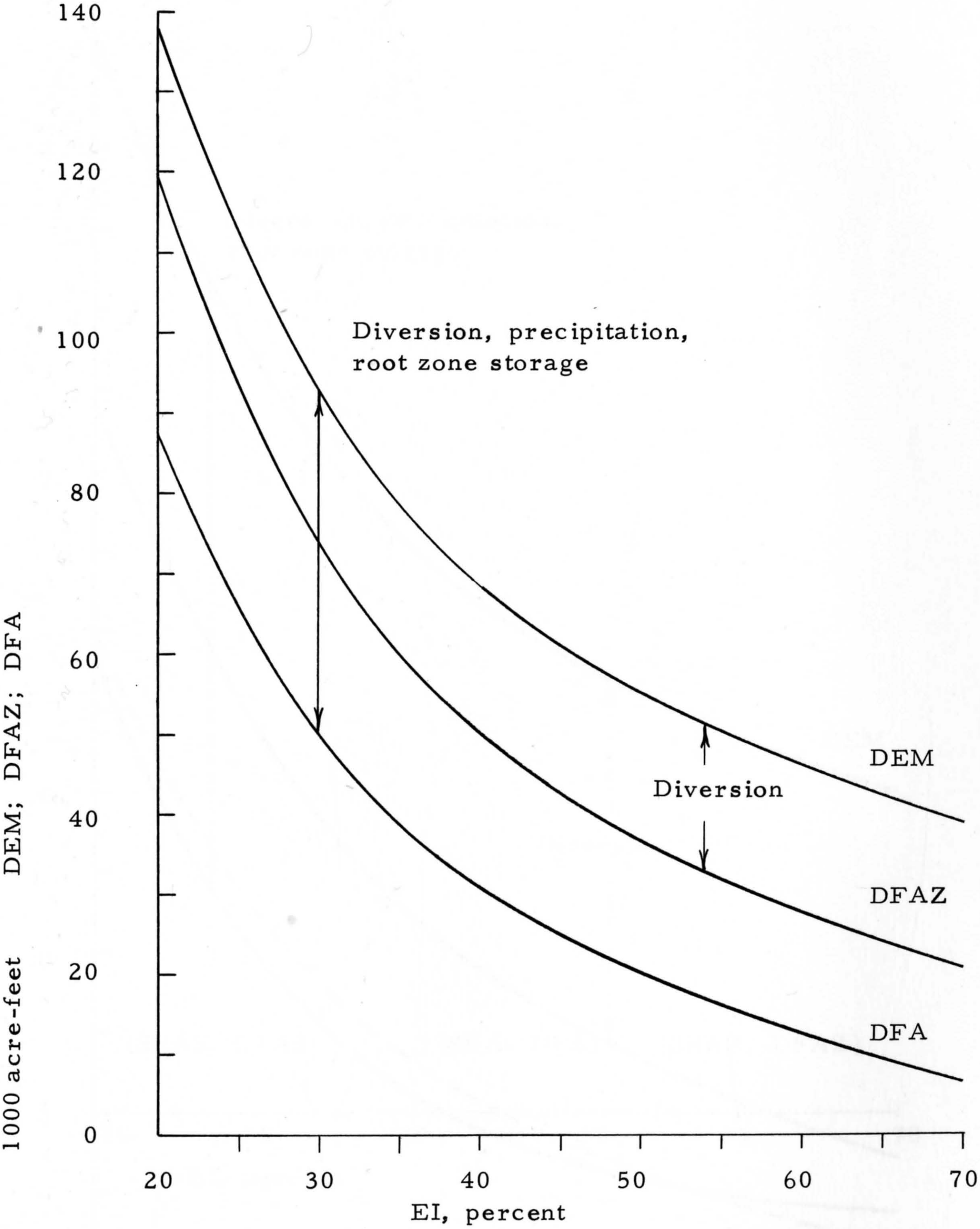

Figure 21. Annual diversion demand (DEM), annual deficit (DFAZ) excluding root zone storage, and annual deficit (DFA) including root zone storage vs irrigation efficiency (EI), Northern Juab Valley subarea.

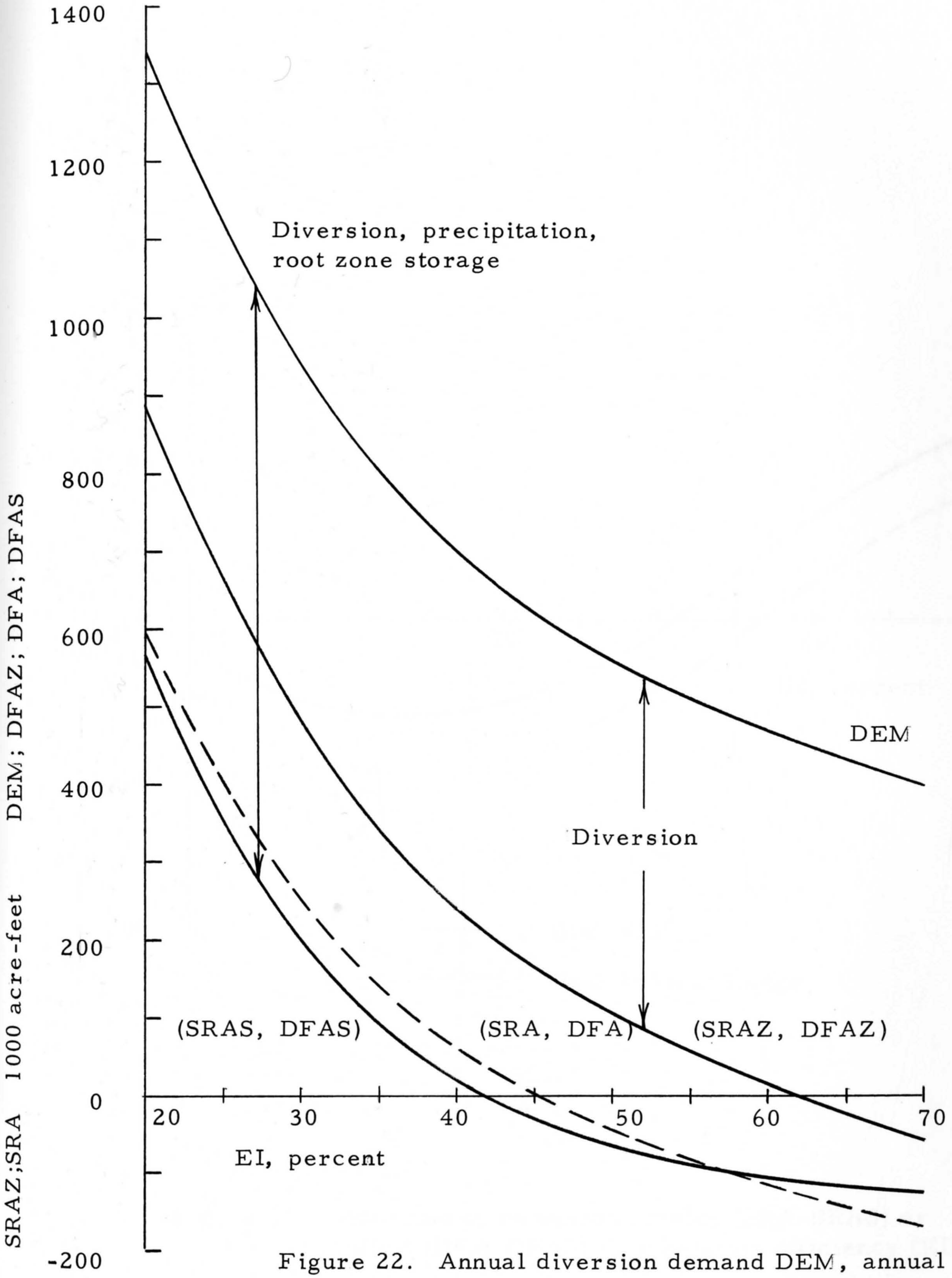

Figure 22. Annual diversion demand DEM, annual surplus (SRAZ) or deficit (DFAZ) excluding root zone storage, and annual surplus (SRA) or deficit (DFA) including root zone storage vs. irrigation efficiency (EI), Utah Lake drainage area.

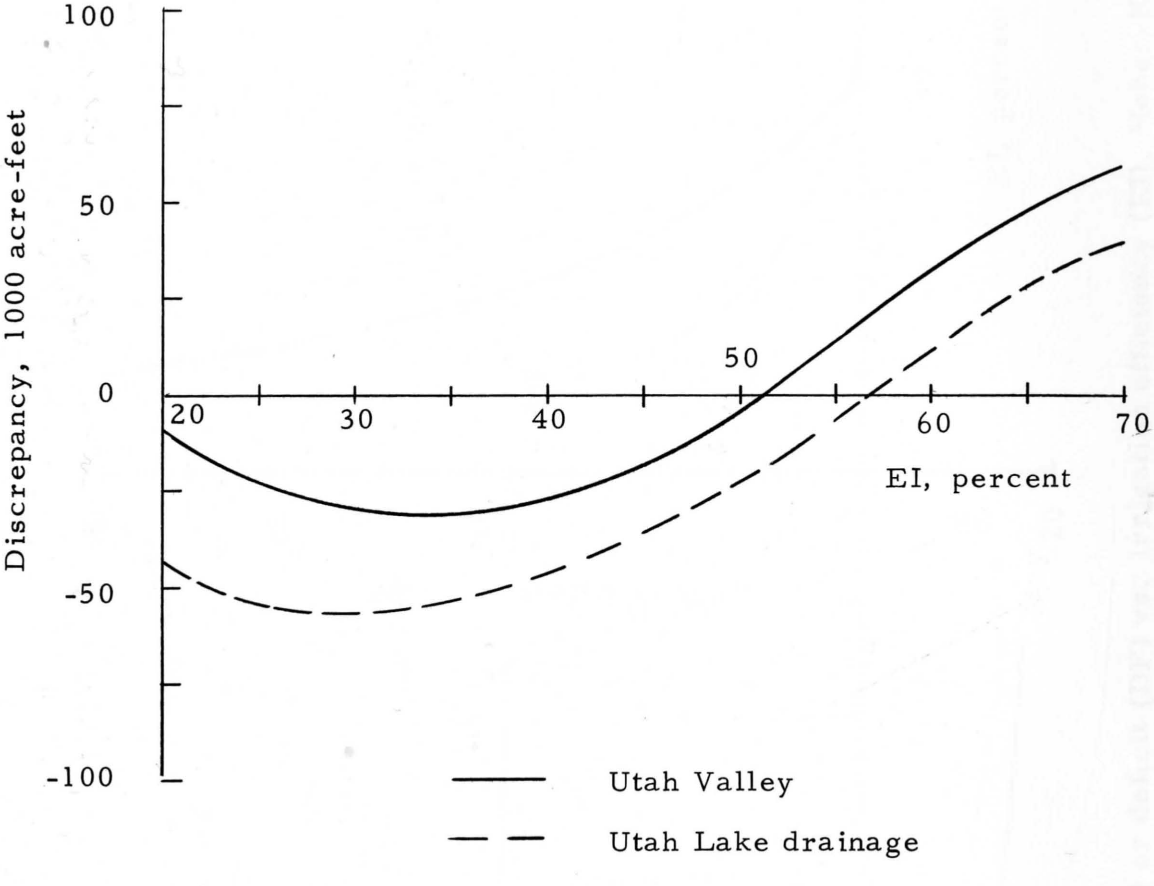

Figure 23. Discrepancy of annual surplus (SRA-SRAS) or deficit (DFA-DFAS) vs irrigation efficiency (EI).

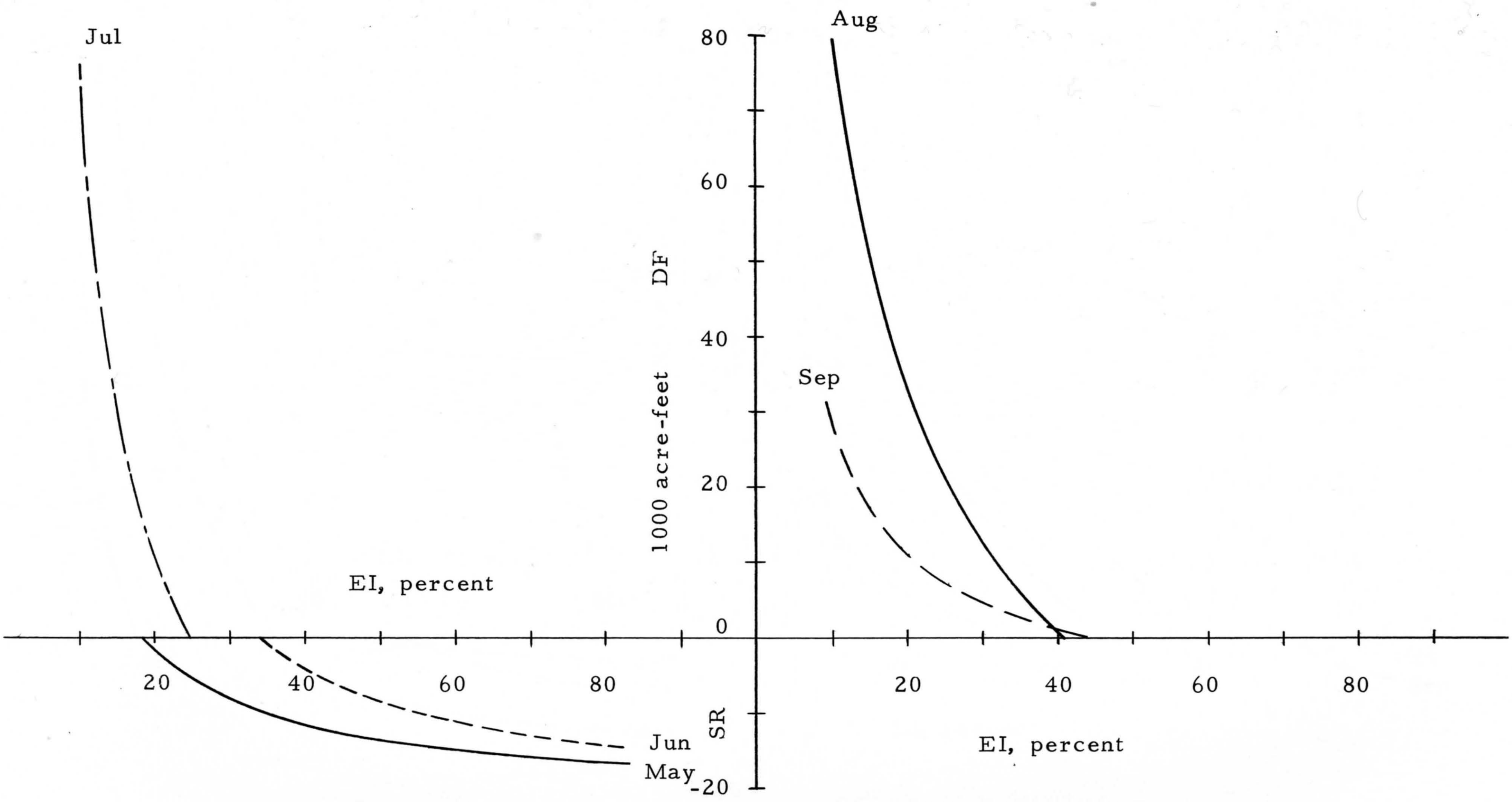

Figure 24. Monthly surplus (SR) or deficit (DF) vs. irrigation efficiency (EI), Heber-Kamas subareas.

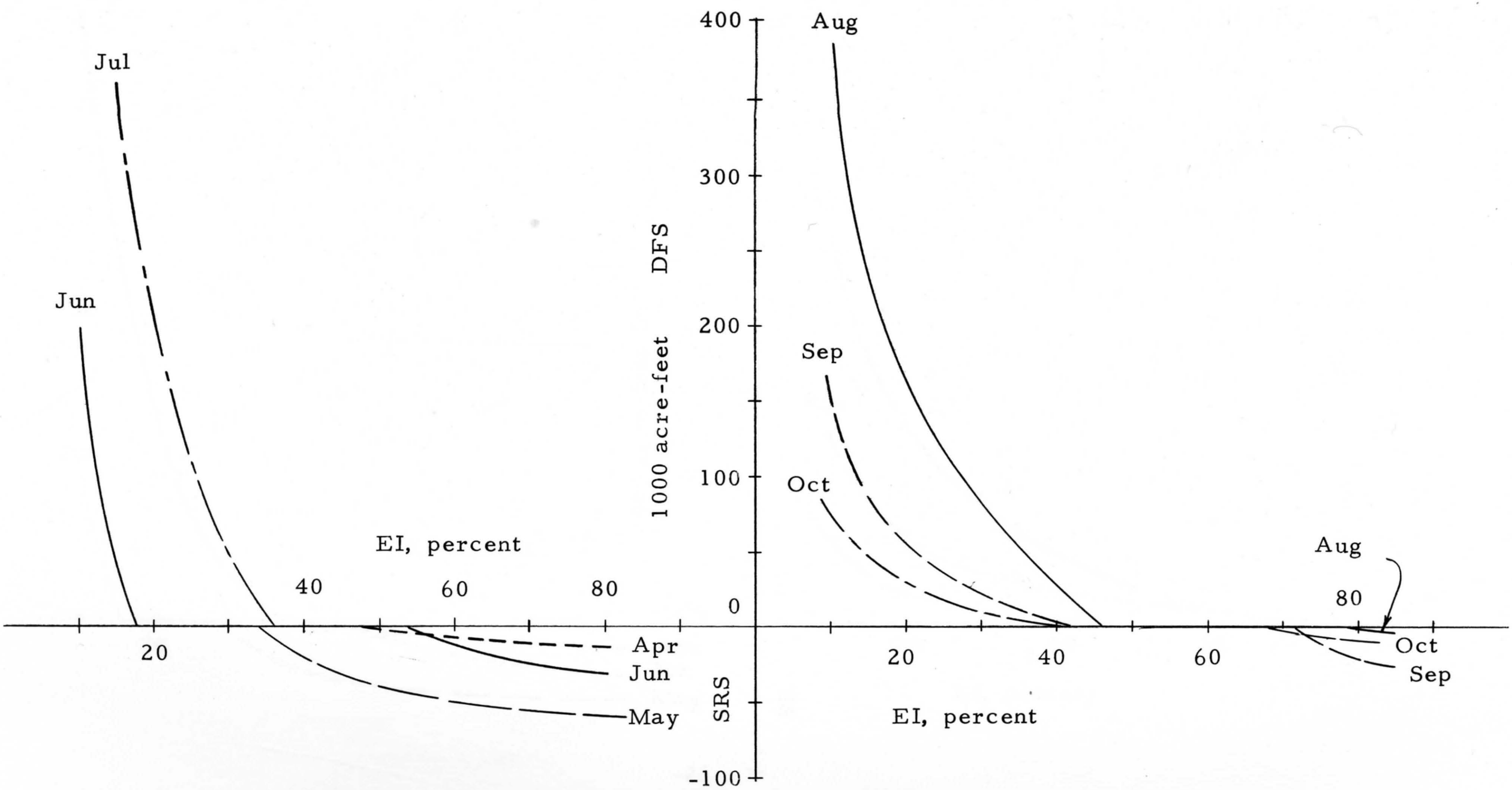

Figure 25. Monthly surplus (SRS) or deficit (DFS) vs. irrigation efficiency (EI), Utah Valley subarea. Water distributed uniformily over entire area.

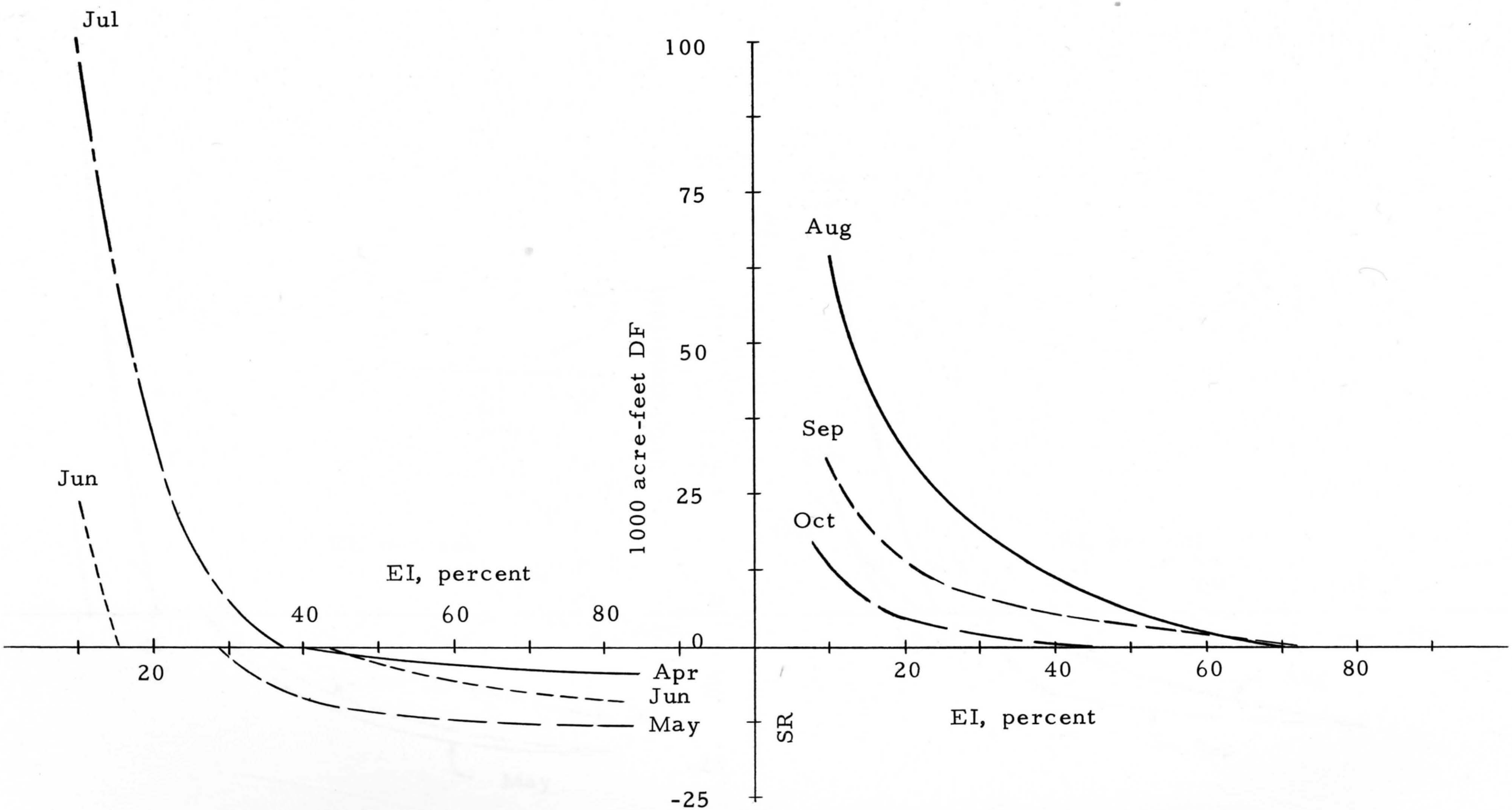

Figure 26. Monthly surplus (SR) or deficit (DF) vs. irrigation efficiency (EI), Lehi-American Fork.

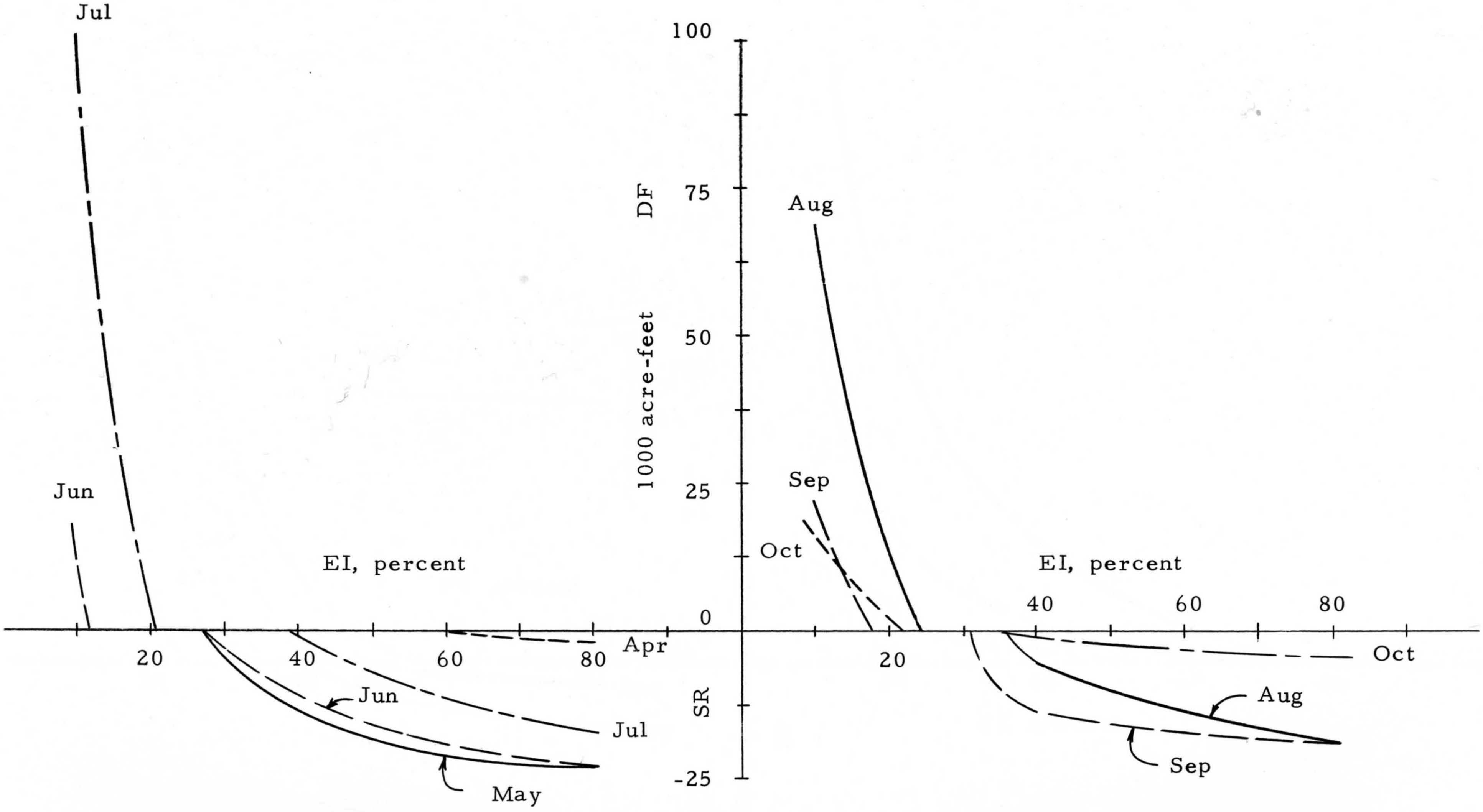

Figure 27. Monthly surplus (SR) or deficit (DF) vs. irrigation efficiency (EI), Provo district.

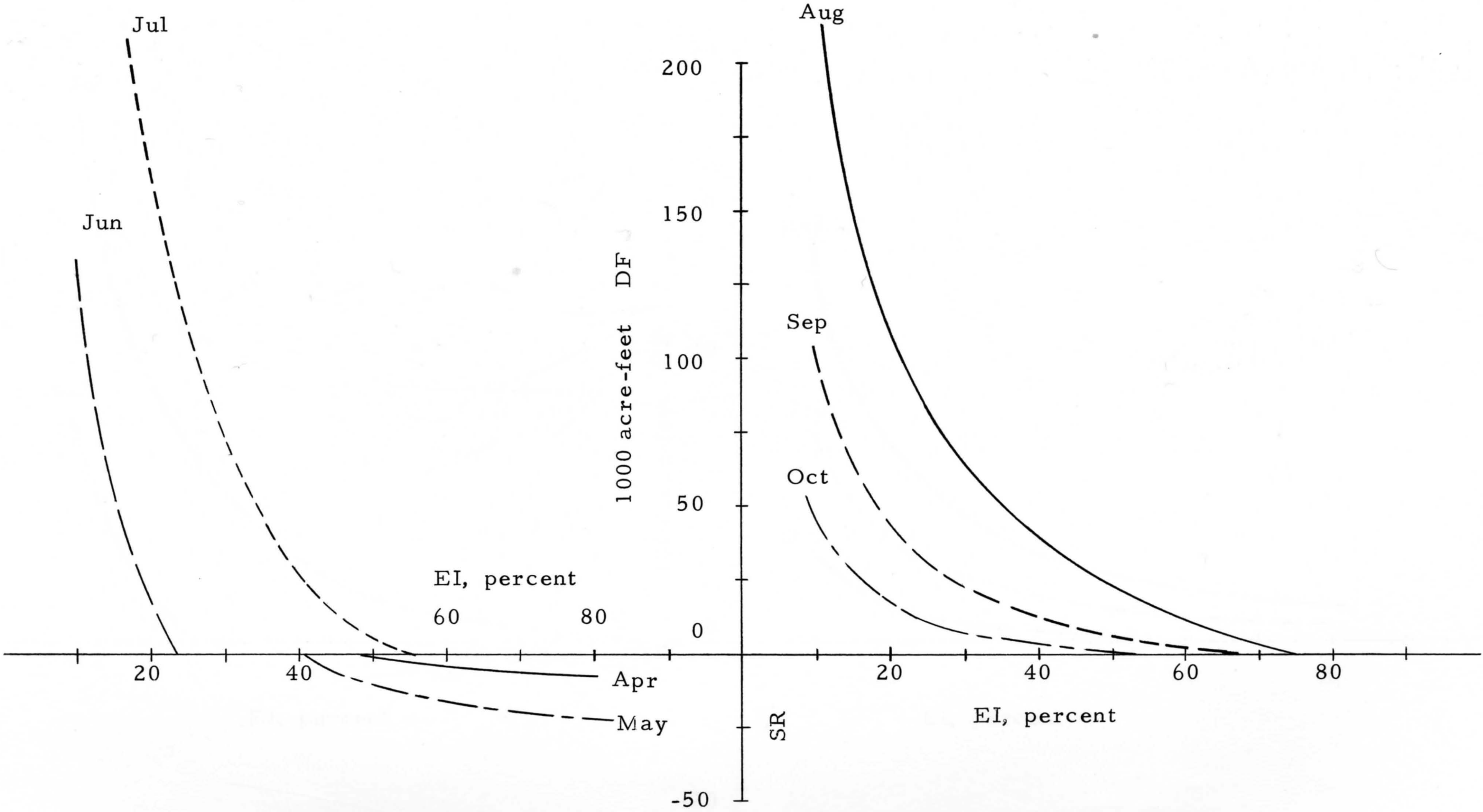

Figure 28. Monthly surplus (SR) or deficit (DF) vs. irrigation efficiency (EI), Spanish Fork district.

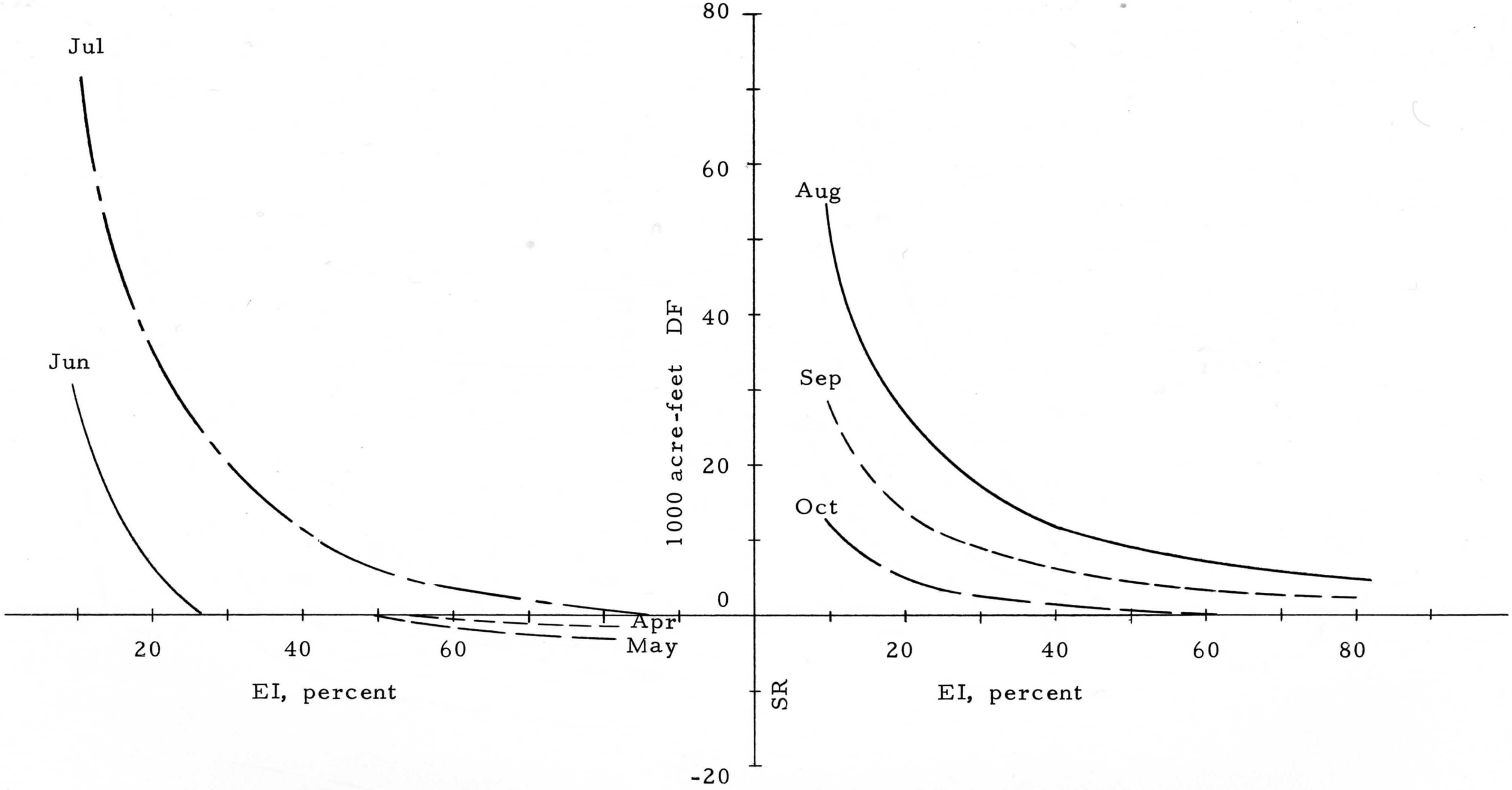

Figure 29. Monthly surplus (SR) or deficit (DF) vs. irrigation efficiency (EI), Northern Juab Valley subarea.

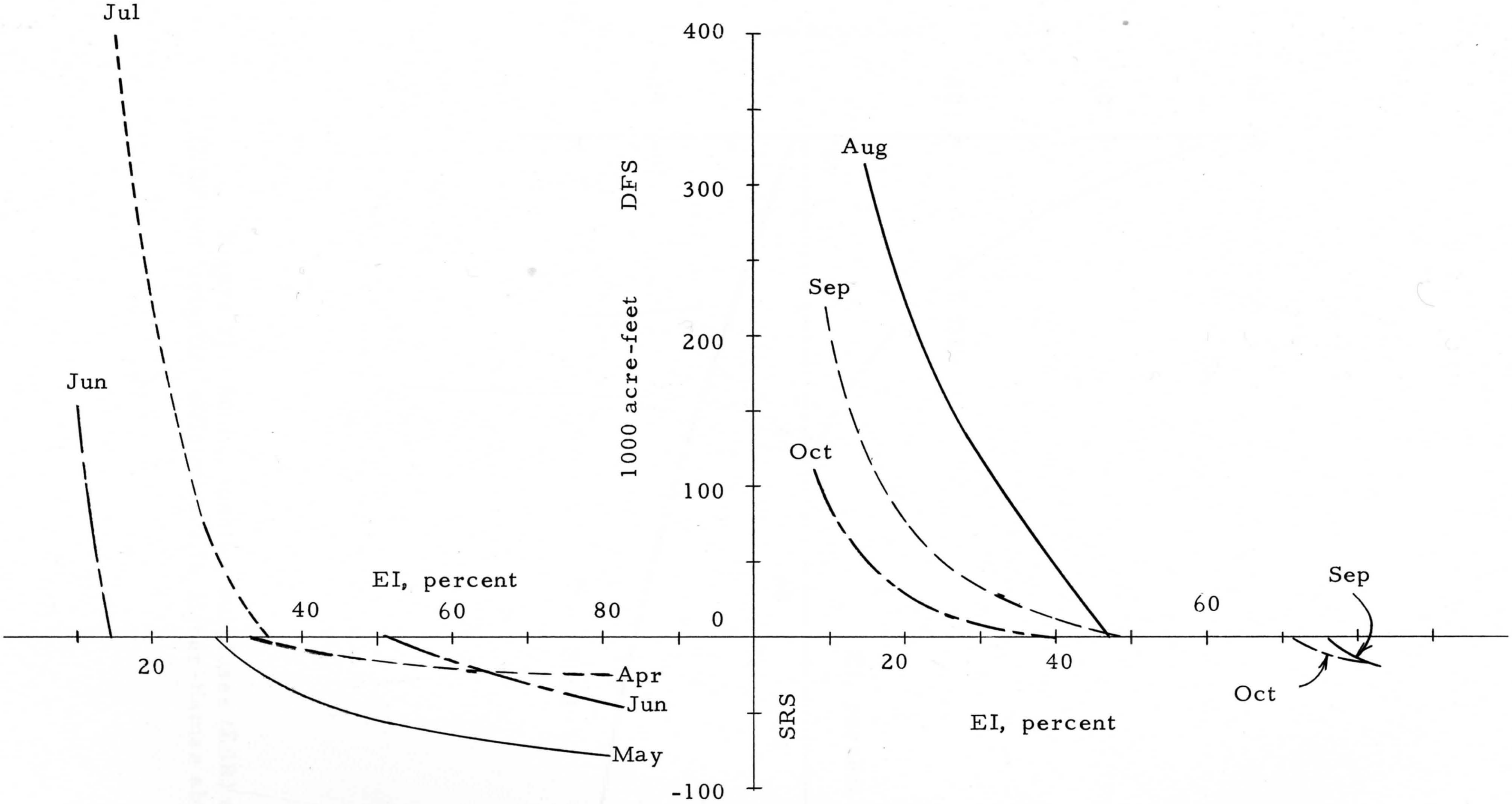

Figure 30. Monthly surplus (SRS) or deficit (DFS) vs. irrigation efficiency (EI), Utah Lake drainage area.

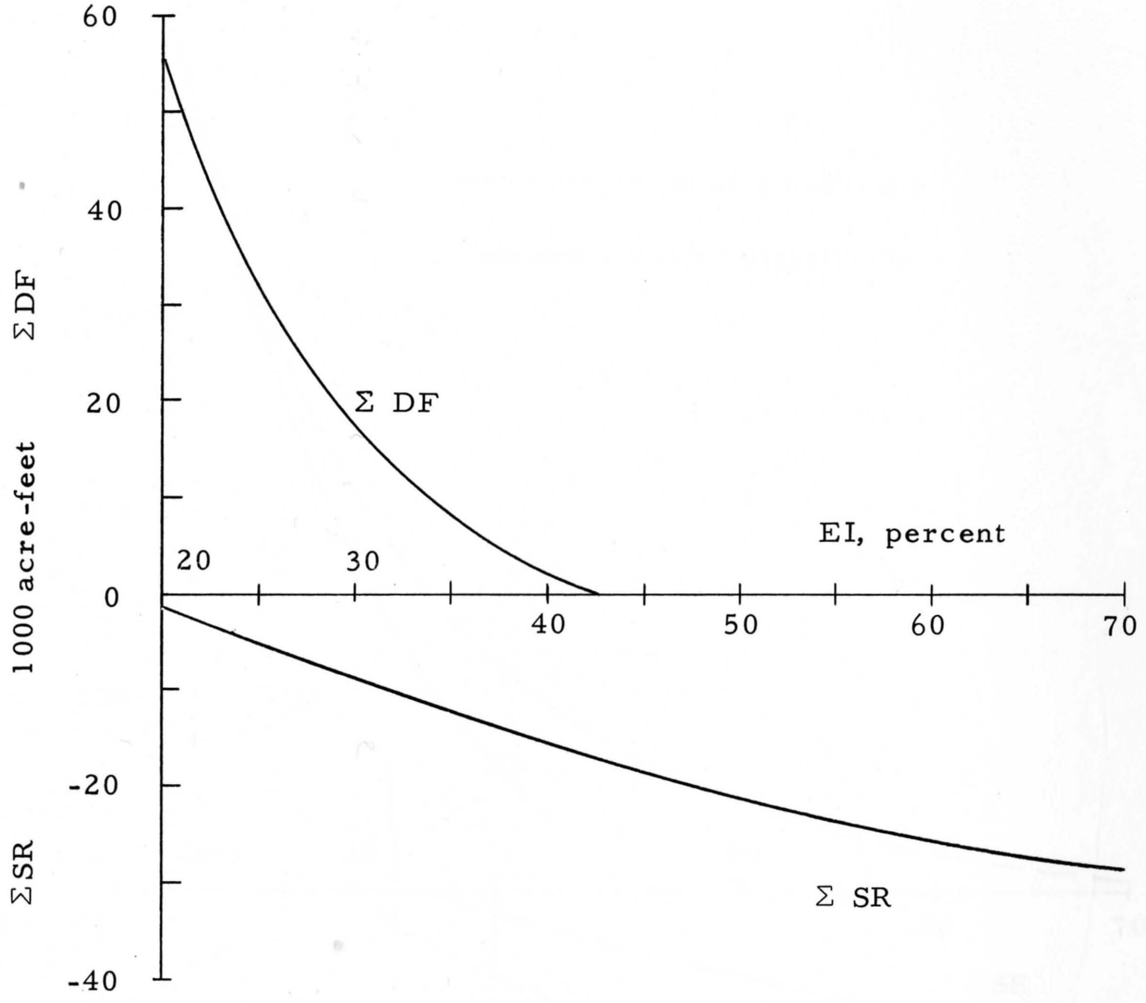

Figure 31. Sum of monthly surpluses (ΣSR) deficits (ΣDF) vs irrigation efficiency (EI), Heber-Kamas sbuareas.

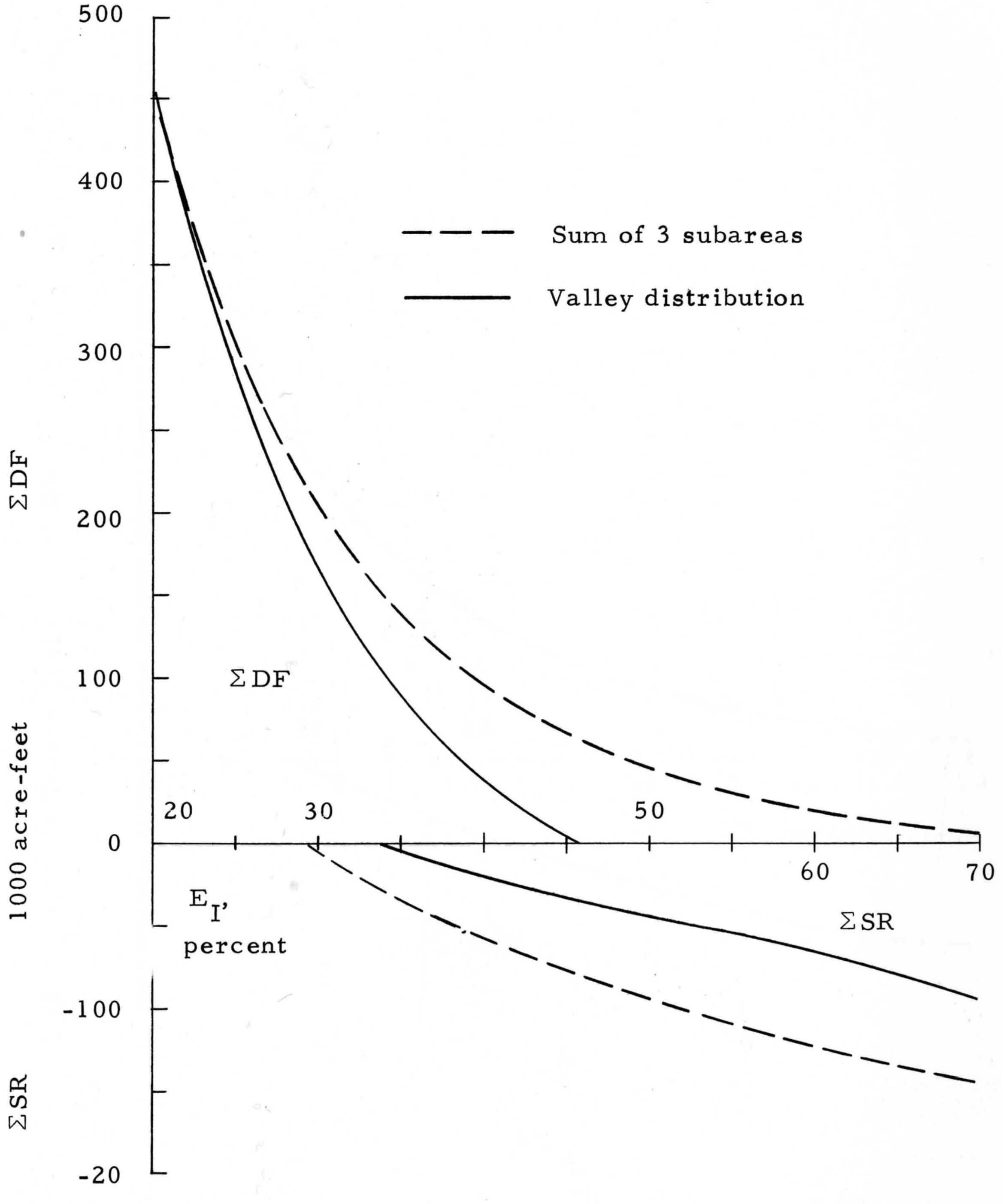

Figure 32. Sum of monthly surpluses (ΣSR) and deficits (ΣDF) vs irrigation efficiency (EI), Utah Valley subarea.

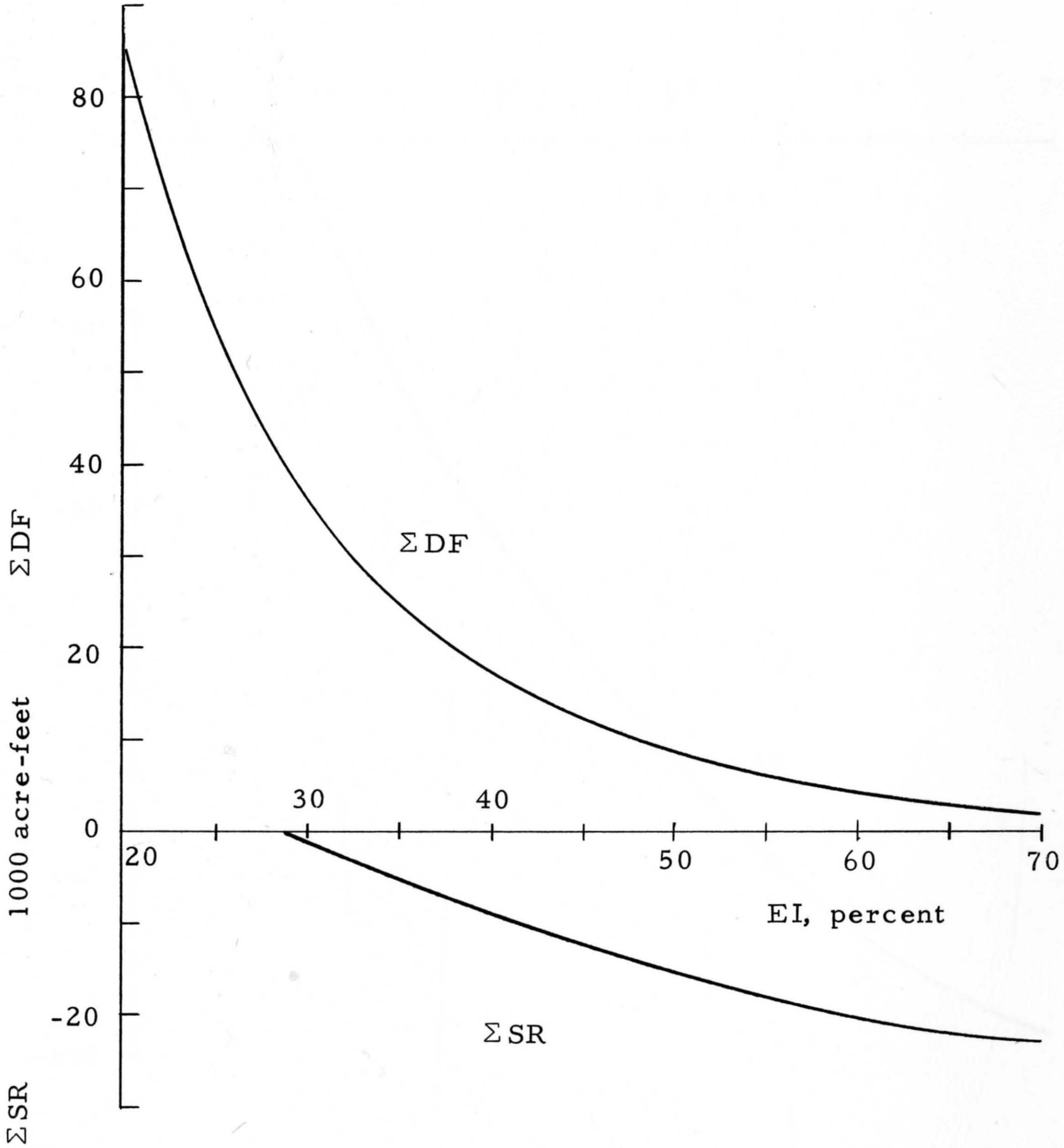

Figure 33. Sum of monthly surpluses (ΣSR) and deficits (ΣDF) vs irrigation efficiency (EI), Lehi-American Fork district.

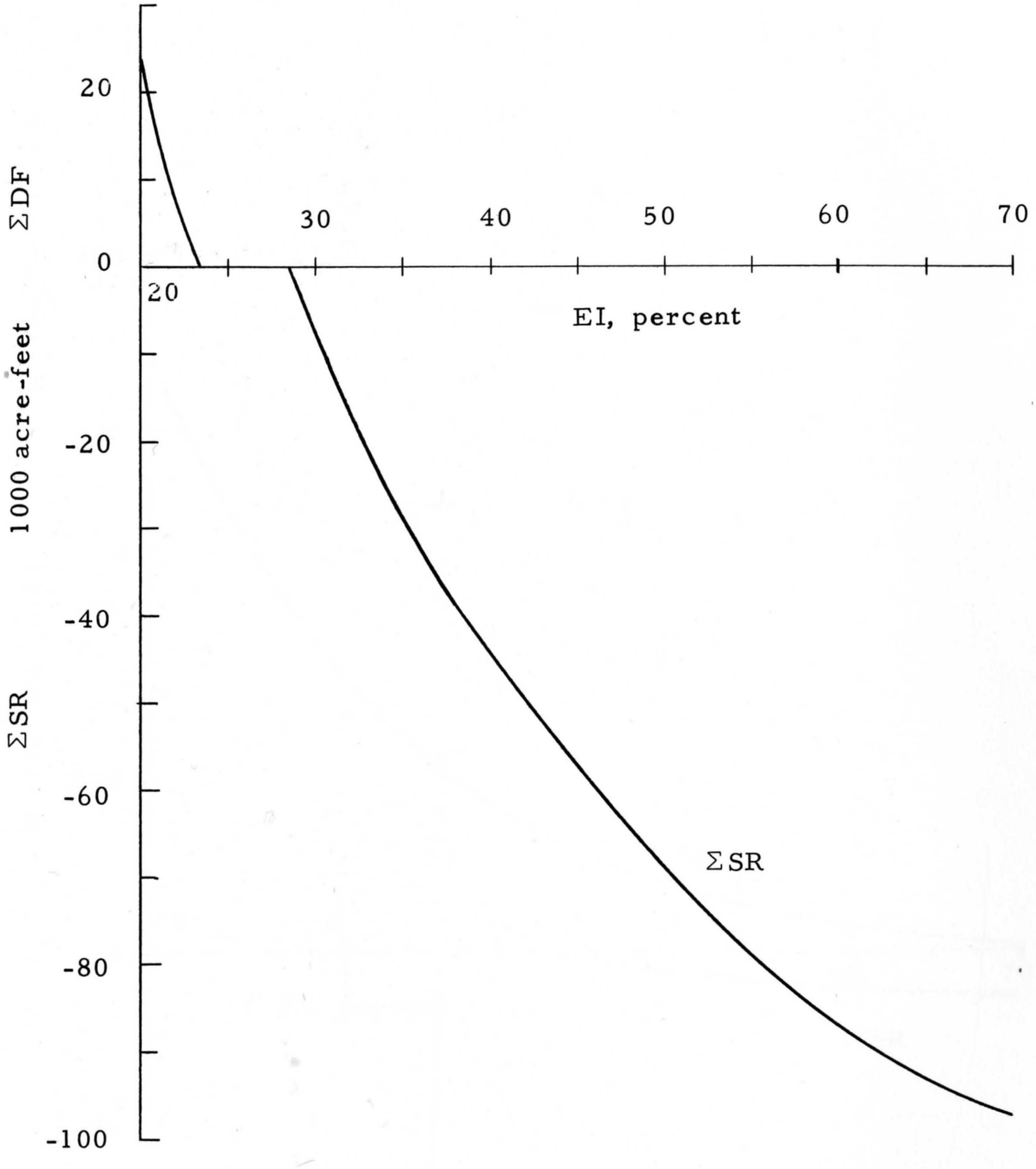

Figure 34. Sum of monthly surpluses (ΣSR) and deficits (ΣDF), vs irrigation efficiency (EI), Provo district.

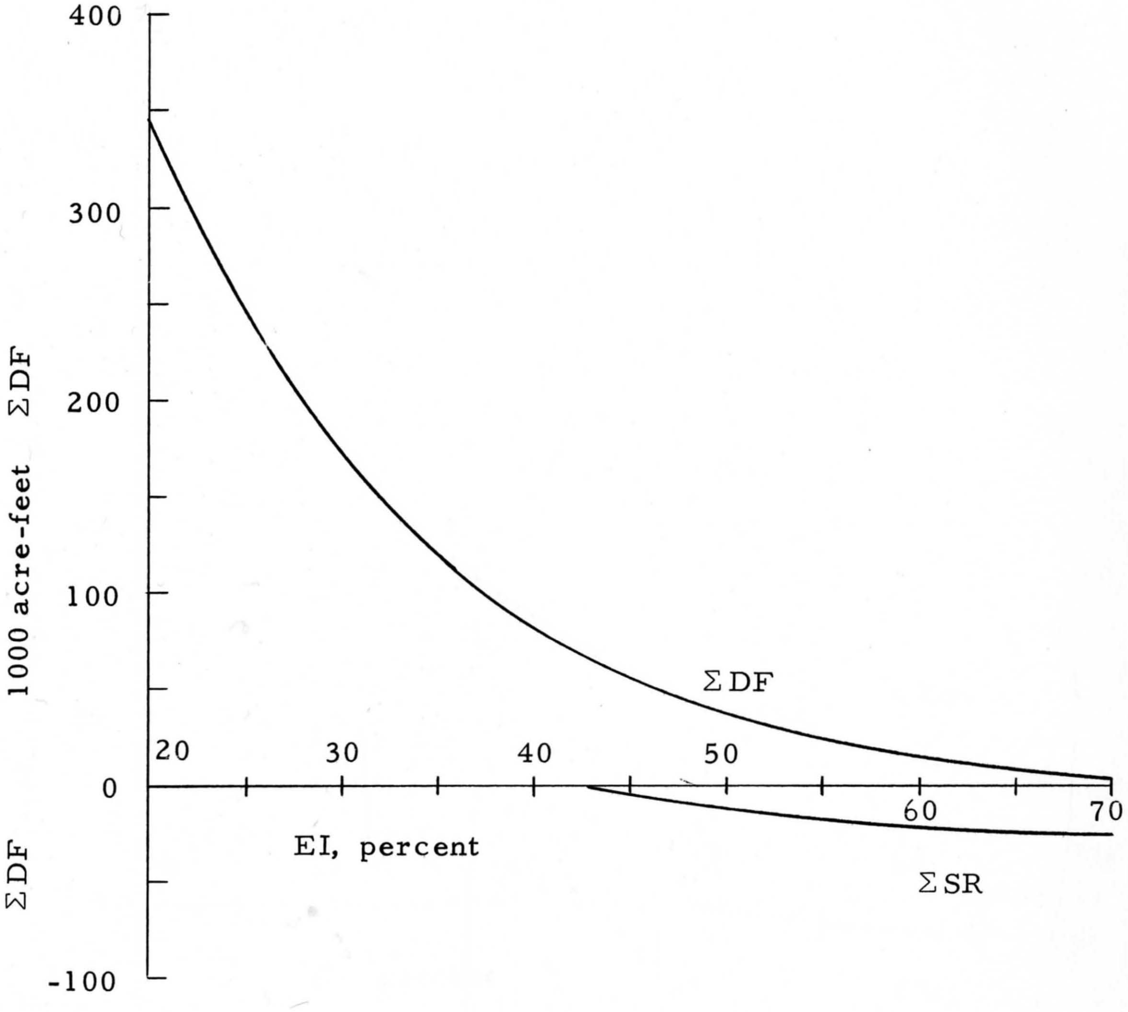

Figure 35. Sum of monthly surpluses (ΣSR) and deficits (ΣDF) vs irrigation efficiency (EI), Spanish Fork district.

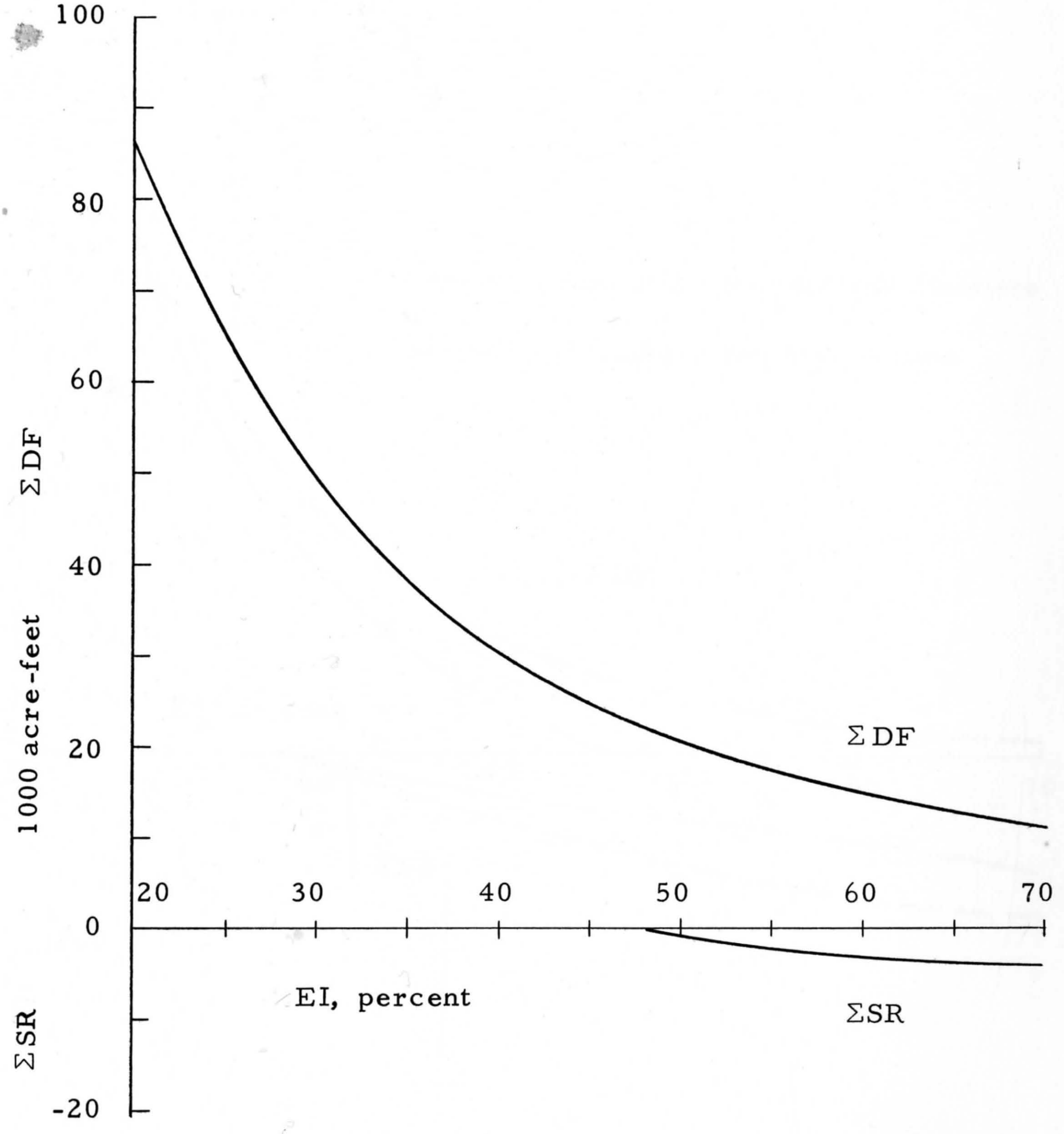

Figure 36. Sum of monthly surpluses (ΣSR) and deficits (ΣDF) vs irrigation efficiency (EI), Northern Juab Valley subarea.

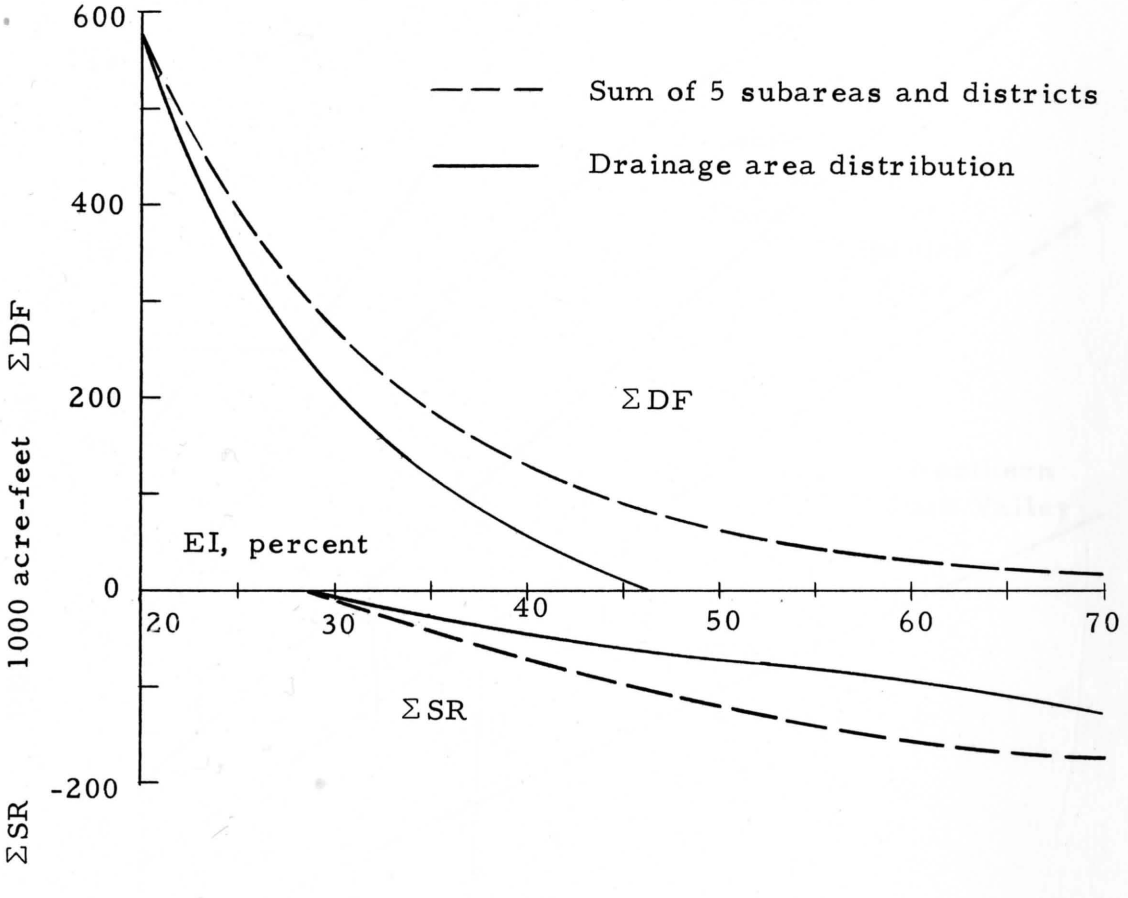

Figure 37. Sum of monthly surpluses (ΣSR) and deficits (ΣDF) vs irrigation efficiency (EI), Utah Lake drainage area.

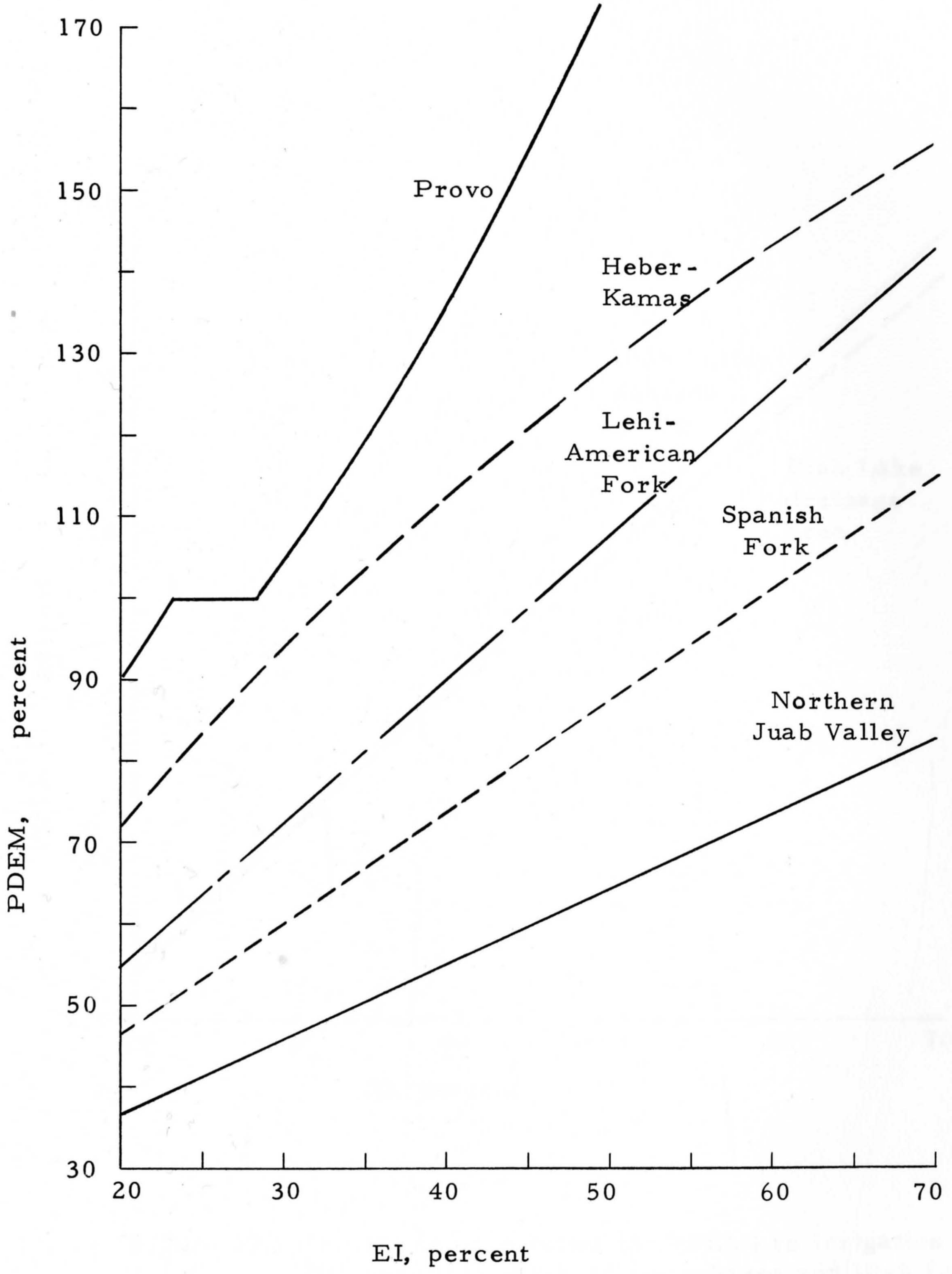

Figure 38. Percent demand satisfied)PDEM) vs irrigation efficiency (EI), Utah Lake subareas and districts.

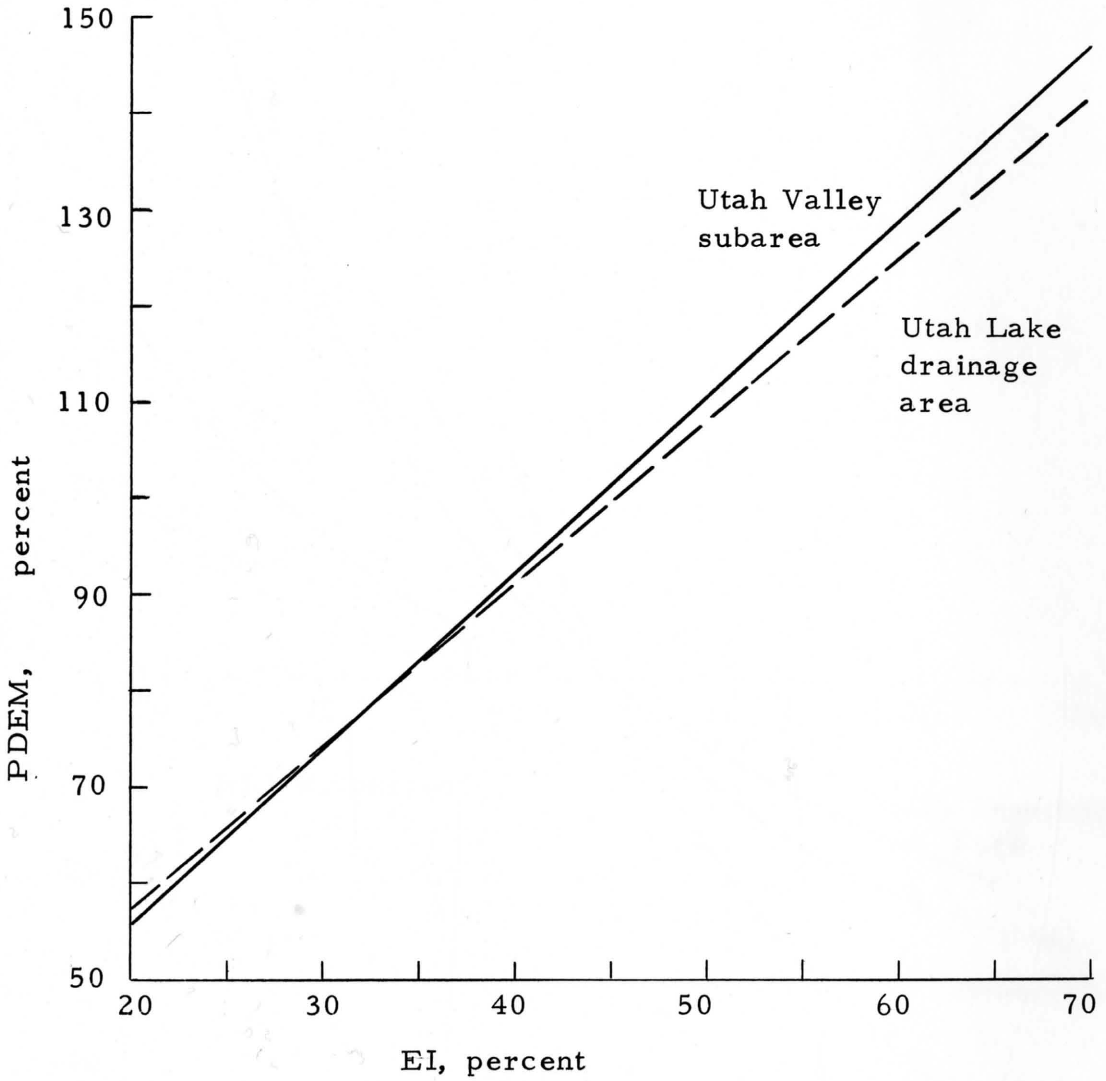

Figure 39. Percent demand satisfied (PDEM) vs irrigation efficiency (EI), Utah Valley subarea and Utah Lake drainage area.

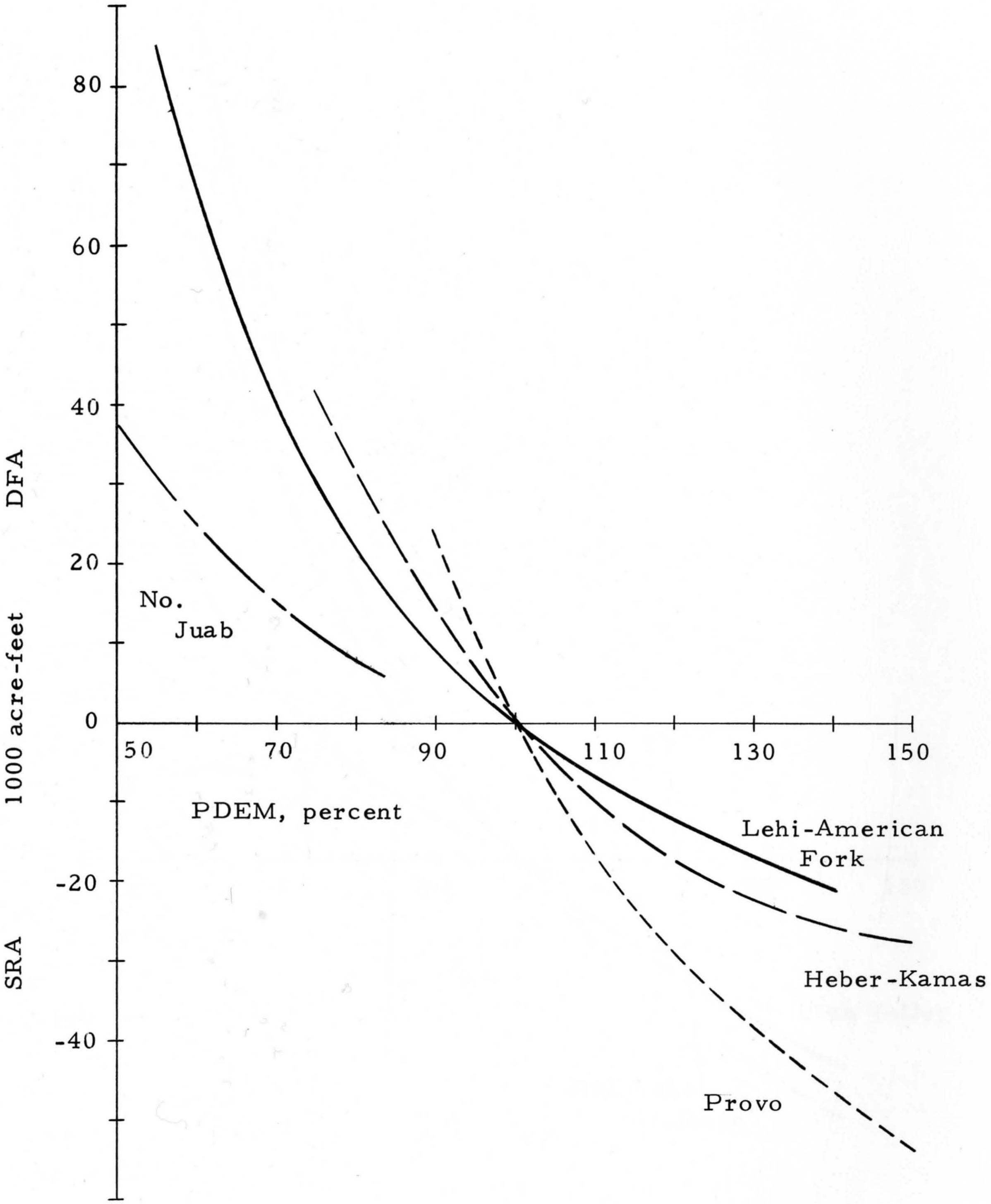

Figure 40. Annual surplus (SRA) or deficit (DFA) vs percent demand satisfied (PDEM) for Heber-Kamas, Lehi-American Fork, Provo, and Northern Juab Valley areas.

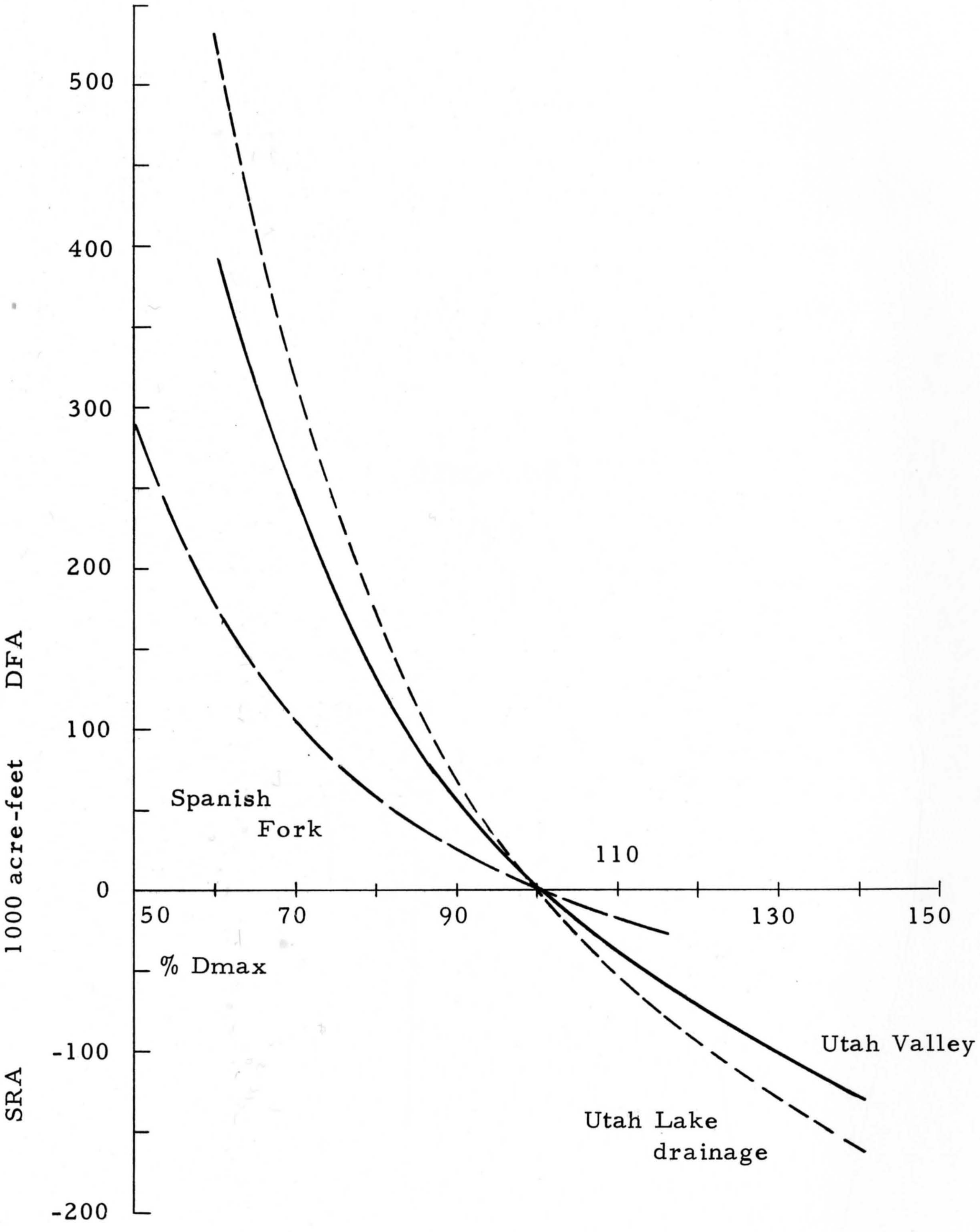

Figure 41. Annual surplus (SRA) or deficit (DFA) vs percent demand satisfied (PDEM), Spanish Fork, Utah Valley, and Utah Lake drainage areas.

Appendix B

Data

DATA

The data was obtained from that assembled for the hydrologic inventory of the Utah Lake drainage area under the direction of Research Project Engineer Gaylord V. Skogerboe. Additional information on specific characteristics and quantities of the Utah Lake drainage area as well as exact sources of data are found in the report by Hyatt, Skogerboe, Haws, and Austin (1968b, to be published). Some of the types of data were

climatic data
- station location and elevation
- monthly precipitation and temperature
- years of record
- percent daylight hours

hydrologic data
- stream gaging station location
- monthly stream runoff
- years of record
- frequency of runoff
- determination of base time period
- groundwater withdrawal and addition
- water quality
- location and quantity of diversions
- municipal and industrial depletion
- phreatophyte depletion

land data
- areas of major canal companies
- type, location, and area of crops and native vegetation
- determination of areas irrigated
- type of soil
- determination of soil moisture capacity

Contained in the following tables is the principle information used in this study on irrigation demand.

Table 33. Canal companies included in Utah Valley districts.

District	Irrigation or Canal Co.	No. on Figures 2 & 3
Lehi-American Fork		
Alpine	Alpine Irrigation Co.	1
American Fork	American Fork Irrigation Co.	2
	Winn Ditch Co.	
Lehi	Lehi Irrigation Co.	3
	Mitchell Hollow Irrig. Co.	
	Spring Creek Irrigation Co.	
North Bench	North Bench Irrigation Co.	4
Pleasant Grove	Pleasant Grove Irrigation Co.	5
	Hollow Water Co.	
	individual rights	
Provo		
Fort Field	Fort Field Irrigation Co.	6
Lake Bottom	Lake Bottom Canal Co.	7
Little Dry Creek	Little Dry Creek Irrigation Co.	8
Provo Bench	Provo Bench Canal and Irrig. Co.	10
Provo City	Provo City Irrigation System	11
	individual water rights	
	P & M - B & Y[a]	
Provo Reservoir	Provo Reservoir Water Users Co.	12
	Utah Lake Distributing Co.	
	North Union Canal Co.	
	Alta Ditch and Canal Co.	
Timpanogas	Timpanogas Canal Co.	13
Upper East Union	Upper East Union Irrigation Co.	14
	East River Bottom Canal Co.	
	Faucett Field Ditch Co.	
West Union	West Union Canal Co.	15
	West Smith Ditch	

[a] Separate diversion records.

[b] Included together with Provo Reservoir Water Users Co. because both use the Provo Res. Canal on the west bank of the Jordan River.

[c] The areas are shown in the maps of Figures 2 and 3.

Table 33. Continued

District	Irrigation or Canal Co.	No. on Figures 2 & 3
Spanish Fork		
East Bench	East Bench Canal Co.	16
Hobble Creek	Little Spring Creek Irrigation Co.	17
	Mill Pond Spring Irrigation Co.	
	Springville City Irrigation Co.	
	Wood Spring Irrigation Co.	
Lake Shore	Lake Shore Irrigation Co.	18
Mapleton	Mapleton Irrigation Co.	19
Mill Race	Spanish Fork Southest Irrigation Co.	20
	Spanish Fork West Field Irrigation Co.	
Salem	Salem Irrigation and Canal Co.	21
Spanish Fork South	Spanish Fork South Irrigation Co.	22
Strawberry	Strawberry Highline Canal (services south Utah Valley)	23
Santaquin	area in vicinity of Santaquin, Utah	--
Elberta	area in vicinity of Elberta, Utah and Goshen Valley	--

Table 34. Crop growth stage coefficients for Utah Lake drainage area, k_c.

Crop[a]	No.	Month						
		Apr	May	Jun	Jul	Aug	Sep	Oct
Alfalfa	A1	0.50	1.08	1.13	1.11	1.06	0.99	0.79
Pasture	A2	0.43	0.90	0.92	0.92	0.91	0.87	0.79
Wild hay	A3	0.43	0.90	0.92	0.92	0.91	0.87	0.79
Grain	A4	0.20	0.48	1.20	1.12	0.40	----	----
Corn[b]	A5	----	0.46	0.64	0.95	1.02	----	----
Sugar beets[c]	A6	0.25	0.79	1.14	1.10	0.83	0.58	0.20
Potatoes[d]	A7	----	0.39	0.77	1.23	1.27	1.02	----
Orchards	A8	0.50	1.07	1.12	1.10	1.06	0.99	0.87
Tomatoes[e]	A10	----	0.22	0.67	0.91	0.80	0.55	----
Small truck[f]	A11	----	0.20	0.65	0.77	0.45	----	----
Idle	A12	----	----	----	----	----	----	----

[a] Crop class A 12 (idle land) is not used in calculation process.
Crops A9 (peas) and A13 (beans) included within crop A11 (small truck).

[b] plant May 20, 100 days

[c] 15 Apr-15 Oct

[d] 15 May-30 Sep

[e] 15 May-30 Sep

[f] 15 May-25 Aug

Table 35. Summary of land use crop pattern.

Area	Percent of Crop Area[a]									
	A1	A2	A3	A4	A5	A6	A7	A8	A10	A11
Lehi-Am. Frk	35.0	15.0	--	25.0	3.0	--	2.0	17.0	--	0.3
Alpine	28.0	24.0	1.0	35.0	4.5	0.8	1.0	3.0	0.5	0.6
Lehi	28.0	19.0	9.0	27.0	7.0	1.0	1.0	2.0	0.2	0.3
No. Bench	34.0	---	---	47.0	1.0	5.0	3.0	---	---	---
Pleas. Grove	28.0	19.0	2.0	22.0	7.0	0.5	0.5	15.0	0.3	0.8
Provo										
Fort Field	24.5	24.5	5.0	22.0	19.5	1.5	0.5	--	0.5	--
Lake Bottom	40.0	23.0	6.0	11.0	13.0	1.0	0.3	5.0	--	0.5
L'L Dry Crk	31.0	38.0	0.5	10.5	18.0	--	--	--	--	1.0
P-M & B-Y	15.0	43.0	5.0	6.7	10.0	1.0	0.5	17.5	--	0.3
Provo Bench	18.0	19.0	2.0	5.5	3.5	--	--	49.0	--	2.0
Provo City	15.0	43.0	5.0	6.7	10.0	1.0	0.5	17.5	--	0.3
Provo Res	24.1	11.0	1.6	29.6	7.0	4.6	2.6	13.0	0.3	1.2
Timpanogos	10.0	28.0	--	3.0	1.5	--	--	56.0	--	0.3
Upper E. Union	6.5	61.0	1.5	2.0	2.0	--	--	27.0	--	--
West Union	21.0	30.5	6.0	10.0	8.0	1.5	0.3	22.0	--	0.5
Spanish Fork										
East Bench	35.7	15.0	3.6	31.2	4.6	--	--	4.8	--	0.1
Hobble Crk	10.7	43.2	19.3	13.1	7.9	4.3	--	0.2	--	--
Lake Shore	26.5	17.2	1.2	39.4	10.2	2.3	--	--	--	0.4
Mapleton	33.7	8.1	1.0	32.4	5.8	2.5	--	9.6	0.5	0.8
Mill Race	23.0	13.8	12.8	32.0	11.8	4.0	--	--	--	0.4
Salem Irrig.	18.1	51.8	5.3	13.8	8.4	.1	0.4	0.3	--	0.6
S.F. South	23.5	19.6	2.1	35.3	14.1	2.8	--	--	--	--
Strawberry	32.9	16.1	4.2	24.0	8.2	0.2	0.8	7.9	--	0.5
Santaquin	28.0	8.0	--	28.0	3.0	--	--	28.0	--	--
Elb-Goshen	30.0	13.0	11.0	20.0	6.0	10.0	2.0	3.0	--	--

Table 35. Continued

Area	Percent of Crop Area[a]									
	A1	A2	A3	A4	A5	A6	A7	A8	A10	A11
Heber-Kamas										
Heber Valley	38.6	51.3	--	10.1	--	--	--	--	--	--
Kamas	32.7	61.6	--	5.7	--	--	--	--	--	--
Northern Juab	43.0	32.0	--	20.0	4.0	--	--	1.0		

[a]Total crop area is determined by the sum of crops A1 to A11.

Table 36. Soil summary.

Area	Soil Type	Soil Moisture in/ft	Soil Moisture Cap, AF
Lehi-Am. Fork			8822
Alpine	fine sandy loam	1.50	740
Am. Fork	silt loam	2.00	2754
Lehi	clay loam & silt loam	1.75	2751
No. Bench	fine sandy loam	1.50	262
Pleas Grove	clay loam	2.00	2315
Provo			11,200
Ft. Field	silt loam	1.75	221
Lk. Bottom	clay loam	2.00	559
L'L Dry Crk	silt loam	1.75	172
P - M & B - Y	clay loam	2.00	65
Provo Bench	silt loam	1.75	1910
Provo City	clay loam	2.00	1010
Provo Res	silty clay	1.75	5482
Timpi	silt loam	1.75	440
Upper E. Union	sand loam	1.50	163
West Union	clay loam	2.00	1178
Spanish Fork			29,979
East Bench	clay loam	2.00	2080
Hobble Crk	sandy loam	1.50	1746
Lk Shore	sand & clay	1.50	1658
Mapleton	clay loam	2.00	1954
Mill Race	silt clay loam	2.00	3768
Salem Irr.	silt loam	1.75	861
S.F. South	clay loam	2.00	3356
Strawberry	silt loam	1.75	8411
Santaquin	clay loam	2.00	1123
Elb.-Goshen	sandy loam & clay loam	1.75	5022
Utah Valley			50,001
Heber-Kamas			9480
Heber	silt loam to clay loam	2.0 top 2' 1.25 next 2'	8380
Kamas	clay loam to sand loam	2.0 top 2 ft. 1.25 next 2 ft.	1100
No. Juab	clay loam to sand loam	1.75	6750
Utah Lake drainage	-----	---	66,231

Table 37. Annual diversion, acre-feet.

Year	Heber-Kamas	Lehi-American Fork	Provo	Spanish Fork	Northern Juab	Utah Lake drainage
1931	45,001	--	--	--	7,000	--
32	73,991	--	--	--	18,100	--
33	64,407	--	--	--	12,300	--
34	33,645	--	--	--	4,900	--
35	--	--	--	--	16,800	--
36	--	--	--	--	28,700	--
37	--	--	--	--	25,700	--
38	--	--	--	--	20,300	--
39	--	--	--	--	16,800	--
40	--	--	--	--	15,100	--
41	--	--	--	--	22,300	--
42	--	--	--	--	29,000	--
43	--	--	--	--	26,300	--
44	--	--	--	--	22,200	--
45	85,478	68,978	132,017[b]	131,691	16,200	434,400[b]
46	74,571	56,580	153,375[b]	154,470	22,700	461,700[b]
47	85,310	65,978	157,768	151,722	18,700	479,500
48	74,148	62,280	145,959	187,730	11,300	481,400
49	85,681	69,578	168,337	162,520	22,400	508,500
50	91,185	67,079	170,846	175,298	17,100	521,500
51	88,410	64,979	178,105	167,737	13,400	512,600
52	91,571	93,168	174,081	229,037	52,000	639,900
53	78,228	55,381	176,029	162,158	18,600	490,400
54	63,694	39,687	145,222	133,130	10,600	392,300
55	77,498	47,985	158,046[c]	144,403	10,800	438,700[c]
56	76,408	54,083	166,478	147,607	12,500	457,100
57	86,531	56,580	153,851	156,384	23,900	477,200

Table 37. Continued

Year	Heber-Kamas	Lehi-American Fork	Provo	Spanish Fork	Northern Juab	Utah Lake drainage
58	75,001	70,378	150,414	163,171	26,000	485,000
59	72,283	36,287	142,785	115,441	8,100	374,900
60	67,507	42,286	140,981	125,274	11,400	387,600
61	a	18,093	69,298	73,681[d]	--	--
62	a	63,578	238,233	128,545[d]	--	--
63	a	45,485	160,557	96,224[d]	--	--
64	a	56,080	158,380	110,755[d]	--	--
65	a	74,776	178,397	144,642[d]	--	--

[a] No data for Kamas (Upper Provo).

[b] No data for P-M & B-Y. Mean 18 yr. record included = 993 AF.

[c] No data for Provo district. Mean 20 yr. recorded inserted.

[d] No data for Elberta-Goshen included. Error is about 14,000AF.

Table 38. Annual potential consumptive use, acre feet.

Year	Heber-Kamas	Lehi-American Fork	Provo	Spanish Fork	Northern Juab	Utah Lake drainage
1931	40,621	---	---	---	27,685	---
32	35,969	---	---	---	25,641	---
33	37,854	---	---	---	25,773	---
34	39,813	---	---	---	28,821	---
35	---	---	---	---	25,474	---
36	---	---	---	---	25,366	---
37	---	---	---	---	25,914	---
38	---	---	---	---	25,226	---
39	---	---	---	---	26,191	---
40	---	---	---	---	27,102	---
41	---	---	---	---	24,573	---
42	---	---	---	---	24,389	---
43	---	---	---	---	25,552	---
44	---	---	---	---	26,668	---
45	33,679	33,112	41,730[b]	114,841	25,993	215,700[b]
46	36,594	39,856	50,029[b]	138,533	28,811	293,800[b]
47	35,094	38,032	47,839	133,320	27,546	281,800
48	35,384	39,046	49,094	136,500	29,466	289,500
49	35,609	39,032	49,085	136,326	28,959	289,000
50	32,674	34,920	43,877	122,515	27,836	261,800
51	34,299	36,954	46,505	129,750	29,353	276,900
52	36,695	40,243	50,609	139,407	30,431	297,400
53	35,561	39,641	49,811	137,577	29,572	292,200
54	37,003	37,187	46,690	131,355	29,627	281,900
55	36,980	35,619	46,830[c]	126,386	28,445	274,300[c]
56	36,639	36,125	45,330	128,727	27,484	274,300
57	35,474	35,937	45,154	127,156	27,123	270,800
58	37,775	37,702	47,407	133,734	29,665	286,300

Table 38. Continued

Year	Heber-Kamas	Lehi-American Fork	Provo	Spanish Fork	Northern Juab	Utah Lake drainage
59	37,212	37,948	47,497	133,214	28,701	284,600
60	37,899	36,806	46,146	131,059	29,572	281,500
61	a	38,840	48,635	112,289[d]	---	---
62	a	35,641	44,789	103,088[d]	---	---
63	a	37,566	47,362	108,620[d]	---	---
64	a	35,837	45,060	103,531[d]	---	---
65	a	35,020	43,934	100,977[d]	---	---

[a]No data for Kamas (Upper Provo) available.

[b]No data for PM-BY. Mean 18 yr recorded included = 278AF.

[c]No data for Provo district. Mean value inserted.

[d]No data for Elberta-Goshen. Mean 20 yr. value included.

Table 39. Mean diversion and potential consumptive use by subareas and districts.

Subarea or District	Mean Diversion, Acre-Feet							
	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
Heber-Kamas	1,600	19,347	22,835	14,787	8,968	6,117	579	74,233
Utah Valley	23,764	82,210	83,597	67,248	53,655	40,571	13,416	364,469
Lehi-Am.Frk	6,694	17,623	17,918	7,235	3,480	2,396	2,240	57,586
Provo	5,298	28,271	34,196	32,518	28,833	23,821	5,109	158,046
Span, Fork	11,985	36,324	31,483	27,495	21,342	14,354	6,114	149,097
Northern Juab	3,957	6,153	4,023	1,747	1,233	787	807	18,707
Utah Lake drain	29,321	107,718	110,455	83,782	63,856	47,475	14,798	457,405

	Mean Crop Potential Consumptive Use, acre-feet							
Heber-Kamas	---	3,980	8,111	11,457	9,130	3,741	---	36,419
Utah Valley	6,804	25,779	46,188	62,131	43,837	20,094	9,827	214,760
Lehi-Am. Frk.	1,196	4,463	8,149	10,862	7,426	3,410	1,685	37,192
Provo	1,502	5,672	9,714	13,216	9,799	4,637	2,288	46,828
Spanish Fork	4,106	15,644	28,325	38,053	26,711	12,047	5,854	130,740
Northern Juab	910	3,265	5,638	7,525	5,633	3,017	1,444	27,432
Utah Lake drain	7,714	32,952	59,937	81,113	58,700	26,852	11,271	278,539

Table 40. Mean diversion by canal companies, acre-feet.

Company/Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual[a]
Alpine	1447	2837	2871	1471	723	514	542	10,405
No. Bench	738	1504	1452	----	----	----	---	3,694
American Fork	1700	5689	5817	2575	1133	753	652	18,319
Lehi	1581	4337	4318	1295	538	381	323	12,773
Pleasant Grove	1228	3256	3460	1894	1086	748	723	12,395
Provo Res.	2321	13,396	16,184	16,829	13,837	11,120	1539	75,226
Provo Bench	1315	6958	8694	7376	7334	6233	1685	39,595
Lake Bottom	22	532	769	745	639	472	116	3,304
Ft. Field	7	194	293	318	310	276	47	1,452
Timpanogos	132	789	932	821	755	662	301	4,411
W. Union	274	1378	1765	1630	1512	1180	251	7,995
Provo City	925	3355	3609	3135	2980	2496	683	17,111
L'L Dry creek	73	467	515	470	440	408	121	2,494
Up. East Union	181	1013	1205	1021	952	838	250	5,465
PM & BY	48	189	230	173	146	136	69	993
Hobble Creek	6310	8215	3266	1559	1197	1019	1019	22,585
Mapleton	32	925	2102	2849	2248	890	89	9,135
E. Bench	402	2703	3059	2608	1977	1123	338	12,269
Mill Race	462	2968	3435	3388	2672	2140	841	15,906
Lk. Shore	506	1906	1680	1032	888	552	131	6,782
Sp. Fork-South	347	4365	3002	2339	2020	1425	651	14,158
Salem Irr.	194	1387	1510	1410	1190	940	314	6,952
Straw High	1478	7746	8941	9196	6815	4360	1447	40,034
Santaquin	885	2660	1857	671	485	443	390	7,391
El-Goshen	1156	3449	2631	2443	1850	1462	894	13,885
Heber	1425	17,475	19,319	12,308	7168	5364	575	63,638
Kamas	175	1872	3516	2479	1800	753	---	10,595
No. Juab	3957	6153	4023	1747	1233	787	807	18,707

[a] Total of 264 AF for Mar and Nov diversion in Utah Lake drainage; 87 AF in Mar for Lake Shore.

Table 41. Mean potential consumptive use by canal companies, acre feet.

Company/Month	Apr	May	Jun	Jul	Aug	Setp	Oct	Annual
Alpine	124	453	787	1046	745	372	182	3709
No. Bench	36	139	305	398	223	88	37	1227
Amer Fork	349	1298	2465	3265	2135	995	471	10,939
Lehi	404	1518	2772	3712	2552	1151	571	12,680
Pl. Grove	283	1055	1820	2441	1772	844	424	8640
Provo Res	687	2651	5032	6782	4550	1989	921	22,612
Provo Bench	285	1011	1526	2042	1670	932	483	7949
Lk. Bot	74	278	443	610	485	235	117	2242
Ft. Field	29	115	206	289	213	84	42	977
Timp	28	161	262	430	386	95	50	1411
W. Union	163	594	932	1264	1009	524	269	4756
Provo City	147	541	830	1140	938	485	252	4334
L'L Dry Crk	26	100	161	225	181	82	42	816
Up. E. Union	54	186	269	361	307	180	96	1455
PM & BY	9	35	53	73	60	31	16	278
Hobble Crk	381	1480	2269	3078	2406	1210	631	11,385
Mapleton	223	843	1589	2101	1383	607	296	7043
E. Bench	265	975	1782	2349	1579	731	366	8047
Mill Race	438	1717	3277	4421	2956	1175	584	14,568
Lk. Shore	246	960	1930	2576	1618	613	303	8240
Sp. Fk. South	363	1454	2859	3875	2535	932	463	12,481
Salem Irr.	159	583	936	1274	999	501	262	4714
Straw High	1186	4458	7825	10,528	7541	3478	1729	36,746
Santaquin	130	490	897	1202	830	417	202	4168
El-Goshen	715	2756	4961	6649	4864	2383	1018	23,347
Heber	---	3454	7190	10,185	8090	3293	---	32,212
Kamas	---	454	921	1272	1040	448	---	4136

Table 42. Monthly surpluses and excesses (SR, DF).

Area	[a]EI	SR (-) & DF (+), 1000 acre-feet							
		May	Jun	Jul	Aug	Sep	Σ	Σ(+)	Σ(-)
Heber-Kamas	80	-16.5	-14.4	-1.9	0	-2.6	-35.5	0	-35.5
	75	-16.2	-13.7	-0.9	0	-1.6	-32.4	0	-32.4
	70	-15.8	-13.0	0	0	-0.2	-29.0	0	-29.0
	60	-14.9	-11.0	0	0	0	-25.9	0	-25.9
	50	-13.6	-8.3	0	0	0	-21.9	0	-21.9
	40	-11.6	-4.3	0	0.5	1.7	-13.7	2.2	-15.9
	30	-8.4	0	0	12.2	4.8	8.7	17.1	-8.4
	23	-4.4	0	3.1	28.6	8.6	35.9	40.3	-4.4
	20	-1.9	0	9.7	34.6	11.0	53.4	55.3	-1.9
	15	0	0	35.6	49.8	17.3	102.7	102.7	0
	10	0	0	77.8	80.2	29.7	176.1	176.1	0

[a] Irrigation efficiency

Table 42. Continued

Area	EI	SR (-) & DF (+), 1000 acre-feet									
		Apr	May	Jun	Jul	Aug	Sep	Oct	Σ	Σ (+)	Σ (-)
Lehi-	80	-4.4	-13.6	-8.8	0	0	0	0	-26.8	0	-26.8
Am.	70	-3.8	-12.8	-7.3	0	0.5	1.6	0	-21.9	2.1	-23.0
Fork	60	-3.0	-11.8	-5.4	0	2.8	2.4	0	-15.1	5.1	-20.2
	50	-1.9	-10.3	-2.7	0	5.9	3.5	0	-5.5	9.4	-14.9
	40	-0.3	-8.0	0	0	10.0	5.2	0.6	7.5	15.8	-8.3
	35	0	-5.6	0	2.0	16.3	6.4	1.2	20.3	25.9	-5.6
	30	0	-1.9	0	7.8	19.8	8.0	2.0	35.8	37.7	-1.9
	20	0	0	0	34.8	32.2	13.7	4.8	85.5	85.5	0
	15	0	0	0.3	64.3	44.6	19.4	7.6	136.3	136.3	0
	10	0	0	23.8	100.5	69.3	30.8	13.2	237.7	237.7	0
Provo	80	-2.0	-23.2	-23.4	-17.0	-18.3	-19.1	-4.0	-107.0	0	-107.0
	70	-1.2	-22.2	-21.6	-14.6	-16.6	-18.3	-3.5	-98.1	0	-98.1
	60	-0.1	-20.8	-19.3	-11.5	-14.2	-17.2	-3.0	-86.2	0	-86.2
	50	0	-17.6	-16.1	-7.1	-11.0	-15.6	-2.2	-69.7	0	-69.7
	40	0	-12.6	-11.2	-0.5	-6.1	-13.3	-1.1	-44.8	0	-44.8
	35	0	-11.1	-7.8	0	0	-10.0	-0.3	-29.1	0	-29.1
	30	0	-4.2	-3.1	0	0	0	0	-7.3	0	-7.3
	25	0	0	0	0	0	0	0	0	0	0
	22	0	0	0	0	6.2	0	0	6.2	6.2	0
	20	0	0	0	2.2	18.4	0	2.9	23.5	23.5	0
	15	0	0	0	38.5	34.7	6.0	8.4	87.6	87.5	0
	12	0	0	0	69.5	51.1	13.7	12.2	146.5	146.5	0
	10	0	0	12.5	98.6	67.4	21.4	16.1	216.0	216.0	0

Table 42. Continued

Area	[a]EI	SR (-) & DF (+), 1000 acre-feet									
		Apr	May	Jun	Jul	Aug	Sep	Oct	Σ	$\Sigma(+)$	$\Sigma(-)$
Spanish Fork	80	-7.5	-22.3	0	0	0	0	0	-29.9	0	-29.9
	70	-6.0	-19.6	0	0	4.6	0	0	-21.0	4.6	-25.6
	60	-4.0	-15.8	0	0	12.6	2.5	0	-4.7	15.1	-19.8
	50	-1.2	-10.6	0	6.8	26.8	6.5	0.5	22.3	34.1	-11.8
	45	0	-6.4	0	14.9	32.8	9.2	1.8	52.2	58.7	-6.4
	40	0	0	0	25.2	39.7	12.6	3.4	80.9	80.9	0
	30	0	0	0	75.6	61.4	22.6	8.3	168.0	168.0	0
	23	0	0	1.6	----	---	---	---	---	---	---
	20	0	0	16.7	159.7	107.0	42.7	18.1	344.2	344.2	0
	10	0	0	128.9	350.0	240.5	102.9	47.4	869.7	869.7	0
No. Juab	80	-1.9	-3.3	0	0.8	4.9	2.4	0	2.9	8.1	-5.2
	70	-1.4	-2.8	0	2.0	5.9	2.9	0	6.7	10.9	-4.2
	60	-0.8	-1.0	0	4.0	7.3	3.7	0.4	12.6	15.3	-2.8
	55	-0.4	-1.5	0	4.5	8.1	4.1	0.6	15.4	17.3	-1.9
	50	0	-0.8	0	5.6	9.1	4.7	0.9	19.5	20.3	-0.8
	40	0	0	0	11.0	12.0	6.2	1.6	30.7	30.7	0
	30	0	0	0	21.2	16.6	8.7	2.8	49.3	49.3	0
	25	0	0	1.8	27.6	20.4	10.7	3.8	64.3	64.3	0
	20	0	0	6.6	35.1	26.0	13.7	5.2	86.6	86.6	0
	10	0	0	30.4	72.7	54.2	28.8	12.4	198.5	198.5	0

[a]Irrigation efficiency

Table 42. Continued

Area	EI[a]	SR (-) & DF (+), 1000 acre-feet									
		Apr	May	Jun	Jul	Aug	Sep	Oct	Σ	Σ (+)	Σ (-)
Utah Valley	80	-13.4	-59.6	-32.3	0	-1.2	-20.7	-9.3	-136.8	0	-136.8
	75	-12.0	-57.4	-28.5	0	0	-11.8	-8.5	-118.1	0	-118.1
	70	-10.4	-54.9	-24.1	0	0	0	-1.6	-91.0	0	-91.0
	60	-6.6	-49.5	-13.1	0	0	0	0	-69.2	0	-69.2
	50	-1.1	-40.2	0	0	0	0	0	-41.3	0	-41.3
	45	0	-32.0	0	0	2.9	0	0	-29.0	2.9	-32.0
	40	0	-20.3	0	0	31.3	4.5	3.0	18.5	38.8	-20.3
	35	0	-5.3	0	4.4	63.4	11.6	6.5	91.3	86.0	-5.3
	30	0	0	0	47.0	84.3	21.2	11.2	163.7	163.7	0
	20	0	0	0	214.3	157.6	54.7	27.6	454.2	454.2	0
	15	0	0	41.6	342.1	230.8	88.2	43.9	746.6	746.6	0
	10	0	0	196.8	549.2	377.3	155.2	76.2	1,355.1	1,355.1	0
Utah Lake drain-age	80	-25.8	-79.0	-44.4	0	0	-12.6	-12.1	-173.9	0	-173.9
	77	-25.1	-77.4	-41.4	0	0	-4.5	-11.6	-160.0	0	-160.0
	75	-24.7	-76.3	-39.4	0	0	0	-9.9	-150.2	0	-150.2
	70	-23.4	-72.1	-33.7	0	0	0	0	-129.2	0	-129.2
	60	-20.2	-65.3	-19.4	0	0	0	0	-104.8	0	-104.8
	55	-18.1	-60.3	-10.3	0	0	0	0	-88.7	0	-88.7
	50	-15.7	-54.3	0	0	0	0	0	-70.0	0	-70.0
	45	-12.6	-47.0	0	0	11.3	4.9	0	-43.5	16.1	-59.6
	40	-8.9	-37.8	0	0	48.4	12.3	2.0	16.0	59.4	-46.7
	35	-4.1	-26.0	0	3.6	91.2	21.9	6.0	92.7	122.8	-30.1
	30	0	-8.1	0	39.2	120.4	34.7	7.5	193.8	201.8	-8.1
	20	0	0	0	233.4	218.2	79.5	30.2	561.2	561.2	0
	15	0	0	0	435.6	316.0	124.2	49.0	924.8	924.8	0
	10	0	0	119.8	720.3	511.7	213.7	86.4	1,652.0	1,652.0	0

[a]Irrigation efficiency.

Table 43. Efficiencies of subareas and districts.

Subarea or District	Conveyance Efficiency	Application Efficiency	Irrigation Efficiency
Heber-Kamas	0.688	0.468	0.32
Heber	0.77	0.51	--
Kamas	0.65	0.35	--
Utah Valley	0.798	0.465	0.37
Lehi-American Fork	0.795	0.408	0.32
Alpine	0.78	0.42	--
American Fork	0.81	0.40	--
Lehi	0.80	0.40	--
No. Bench	0.78	0.40	--
Pleasant Grove	0.80	0.42	--
Provo	0.780	0.446	0.35
Ft. Field	0.80	0.45	--
Lake Bottom	0.80	0.42	--
L'L Dry Crk.	0.80	0.45	--
P-M & B-Y	0.80	0.47	--
Provo Bench	0.80	0.51	--
Provo City	0.80	0.47	--
Provo Res.	0.76	0.40	--
Timpanogos	0.80	0.58	--
Upper E. Union	0.80	0.49	--
West Union	0.80	0.47	--
Spanish Fork	0.815	0.509	0.42
East Bench	0.80	0.50	--
Hobble Crk.	0.80	0.40	---
Lake Shore	0.80	0.48	--
Mapleton	0.80	0.51	--
Mill Race	0.80	0.50	--
Salem Irrig.	0.80	0.46	--
Sp. Fork South	0.80	0.50	--
Strawberry	0.85	0.53	--
Santaquin	0.80	0.57	--
Elb.-Goshen	0.84	0.54	--
Northern Juab	0.70	0.50	0.35
Utah Lake drainage	0.775	0.463	0.36

VITA

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